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Are Icons Pictures or Logographical Words? Statistical, Behavioral, and Neuroimaging Measures of Semantic Interpretations of Four Types of Visual Information

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Are Icons Pictures or Logographical Words? Statistical, Behavioral, and Neuroimaging Measures of Semantic Interpretations of Four Types of Visual Information

by

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Dedication

To my family, friends, and those who have accompanied me in this pursuit of knowledge.

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Are Icons Pictures or Logographical Words? Statistical, Behavioral, and Neuroimaging Measures of Semantic Interpretations of Four Types of Visual Information

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This dissertation is composed of three studies that use statistical, behavioral, and neuroimaging methods to investigate Chinese and English speakers' semantic interpretations of four types of visual information including icons, single Chinese characters, single English words, and pictures. The goal is to examine whether people cognitively process icons as logographical words.

By collecting survey data from 211 participants, the first study investigated how differently these four types of visual information can express specific meanings without ambiguity on a quantitative scale. In the second study, 78 subjects participated in a behavioral experiment that measured how fast people could correctly interpret the meaning of these four types of visual information in order to estimate the differences in

reaction times needed to process these stimuli. The third study employed functional magnetic resonance imaging (fMRI) with 20 participants selected from the second study to identify brain regions that were needed to process these four types of visual information in order to determine if the same or different neural networks were required to process these stimuli.

Findings suggest that 1) similar to pictures, icons are statistically more ambiguous than English words and Chinese characters to convey the immediate semantics of objects and concepts; 2) English words and Chinese characters are more effective and efficient than icons and pictures to convey the immediate semantics of objects and concepts in terms of people's behavioral responses, and 3) according to the neuroimaging data, icons and pictures require more resources of the brain than texts, and the pattern of neural correlates under the condition of reading icons is different from the condition of reading Chinese characters.

In conclusion, icons are not cognitively processed as logographical words like Chinese characters although they both stimulate the semantic system in the brain that is needed for language processing. Chinese characters and English words are more evolved and advanced symbols that are less ambiguous, more efficient and easier for a literate brain to understand, whereas graphical representations of objects and concepts such as icons and pictures do not always provide immediate and unambiguous access to meanings and are prone to various interpretations.

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Chapter One: Introduction

Icons: Are They Pictures or Logographical Words?

Icons (i.e., symbolic signs of objects and concepts) are important visual representations of information in modern graphical user interfaces (GUIs) and traffic instructions. By the definition of Horton (1994), icons are small images that represent objects or commands in modern GUIs. Unlike pictures such as generic photographs that are open to various interpretations, Abdullah and Hübner (2006) assert that icons such as pictograms are designed to have an unmistakable meaning that they are supposed to convey. Icons are often designed with a purpose to associate a symbol with a certain meaning like ancient iconography conveying semantics of objects and concepts in the formal development of logographical languages (Sassoon & Gaur, 1997). Although an icon is a small image, it represents a single object or concept like a word rather than "being worth a thousand words" like a generic picture.

Because icons are graphical representations like pictures and are often used to supplement texts, such relations create a challenge for researchers to clarify how people recognize and comprehend an icon. A common question asked by researchers is whether people read icons as images or words. For example, Horton (1994) suggested that reading symbolic information such as an icon demands more of people's visual perception to understand its graphic elements. On the other hand, Haramundanis (1996) suggested that icons are like logographical words (also called "logograms" e.g., Egyptian hieroglyphs, Maya glyphs, or Chinese characters) and learning the meaning of an icon is like learning to read a single logogram of a logographical language. It is plausible that people read icons as symbolic words for the reason that they are designed with a certain graphical style to convey a certain meaning just as the writing system of logographical language used a single graphical symbol as a word in ancient times.

While Haramundanis objected to the idea that icons immediately convey meanings via visual representations of information, Pedell (1996) indicated that through learning and retention, icons could stand alone and provide visual shorthand to meanings without referring to their labels or text definitions later. Deriving from Haramundanis and Pedell's arguments about icon independence, a hypothesis can be proposed: icons can stand alone as logographical words after learning and retention, and people would read icons as they read single logograms. This dissertation aims to investigate this hypothesis by seeking the answer to a fundamental research question: are icons pictures or logograms in terms of how people read them?

Theoretical Perspectives in Semiotics

Since the scope of such a research question is fairly complex, to determine whether icons are pictures or logograms in terms of how people read them requires theoretical perspectives about how signs work in a communicative situation.

Viewing the entire universe as an extended network of signs, Charles S. Peirce (1839-1914) tried to find a proposition of epistemology of how meanings are created and understood through analysis of signs and their use. Peirce proposed a thesis known as the study of semiotics that divided all signs into three components that form a triadic relation. Morris (1938) later designated these three components as the syntactic, pragmatic, and semantic dimensions of a semiotic sign. Figure 1.1 shows the Peirce-Morris model of a semiotic sign and the corresponding dimensions base on the Ogden Triangle (cf. Johansen, 1993, p.62; Ogden & Richards, 1923).

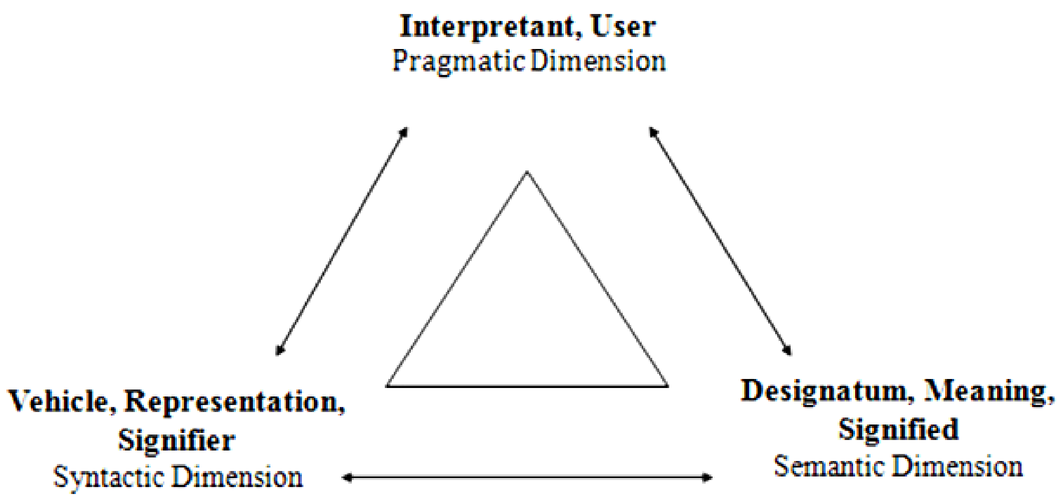

Figure 1.1 Peirce-Morris Semiotic Triangle

The semiotic triangle illustrates three relations among the user, the representation, and the meaning of a sign. Such relations are created by the user's establishing of the connection between the act of understanding representative symbols or objects and the production of signified meanings in a functional communicative environment (Huang & Bias, 2011). This dissertation adapts definitions in the Peirce-Morris model of a semiotic sign to study its research question in terms of its syntactic, pragmatic, and semantic dimensions.

Research Question

As mentioned, this dissertation aims to answer an overarching research question, "Are icons processed as pictures or logographical words by people?" To make logical contrasts and determine whether icons are pictures or logograms in terms of how people interpret them, this dissertation examines how English and Chinese speakers deduce semantic meanings from four different types of visual stimuli including icons, logograms (Chinese characters), pictures, and words (English words), with a hypothesis that people cognitively process icons as logographical words instead of as pictures. In addition, this overarching question is divided into three questions that correspond to the syntactic, pragmatic, and semantic dimensions of semiotics as illustrated in the previous section.

The syntactic dimension of the research question concerns relations among signs in their forms and structures—how well do icons represent semantics of objects and concepts in contrast to other types of visual information? The pragmatic dimension of the research question concerns the relation between signs and the effects they have on the people who use them—how do people respond to icons in a behavioral task in contrast to other types of visual information? The semantic dimension of the research question concerns relations between signs and the meanings to which they refer—how does the brain process icons cognitively to understand their meanings in contrast to other types of visual information?

Since there are three questions, this dissertation includes a series of three studies to answer these questions about the human processing of icons in contrast to other types of visual information. These three studies employ methodologies in survey statistics, behavioral study, and neuroimaging research. A more detailed overview of using statistical, behavioral, and neuroimaging measures to investigate how people process these four types of visual information is explained in Chapter Three.

Conclusion

The goal of this dissertation is to understand how people process icons. It aims to contribute to a better understanding of human factors in human-computer interaction (HCI) and the role of graphical and textual information in human activities that involve the use of social media. Findings of statistical, behavioral, and neuroimaging data in this dissertation also have the potential to inform the research of neuroergonomics (Parasuraman, 2003) and the development of neuroadaptive interfaces (Hettinger et al., 2003) that are human-machine systems that can dynamically adapt different users’ variations in behavioral and cognitive states according to corresponding neural sources of information from the user in the future.

The following chapter of this dissertation provides discussions about the relation between icons and texts and reasons why modern icons can be regarded as logographical words by reviewing literatures of iconography and the formal development of logographical languages. Chapter Two also reviews studies in icon taxonomy, behavioral experiments of using icons in HCI, and neuroimaging research about the semantic system in the brain to see current discourses in syntactic, pragmatic, and semantic dimensions of how people process icons.

Chapter Three formally describes this dissertation’s research questions, designated studies, and objectives. Chapter Three also defines independent and dependent variables for all three studies and explains how the main hypothesis of this dissertation is tested.

Chapter Four documents the first study in which survey data from a sample of 211 participants are collected to glean an empirical understanding of whether people perceived certain stimuli as representing “concrete” objects or “abstract” concepts. Chapter Five describes the second study, a behavioral experiment designed to collect performance data (time on task and error rates) from 78 participants on such semantic judgments. The data from the second study help guide the understanding of which types of visual stimuli are harder or easier for humans to read and judge. The data from the second study also provide corroborating evidence when compared with the subsequent fMRI data collected while 20 test participants selected from the second study make semantic judgments (concrete vs. abstract) upon icons (and other visual stimuli) in the third study described in Chapter Six.

It is the author’s hope and belief that these three studies will afford a new and valuable window onto human processing of icons.

Chapter Two: Literature Review

Every day, people encounter different types of signs. Drivers follow traffic signs; users click icons in a GUI; customers wonder if that Japanese kanji on the restaurant's menu really means sushi, and folks tag friends in pictures on social networks to share precious memories with each other. A person can derive meanings out of these signs and interact with them without knowing that his/her behaviors are affected by them and his/her brain is processing them with complex neural mechanisms underlying his/her cognitive abilities.

How humans process signs is always of interest among different scientific fields including information science, cognitive neuroscience, and linguistics. A common topic among these fields is to investigate how people read a sign (e.g., an icon, a word, or a picture) and understand what it means. To understand how human icon processing works, Chapter Two reviews literatures about 1) how icons evolve and become texts, 2) how icons affect behaviors and cognition, and 3) how the brain generates meanings from icons—to reflect syntactic, pragmatic, and semantic aspects of human icon processing.

Syntactic Representations: How Icons Evolve and Become Texts

The Relationship between Icons and Logograms

The relationship between icons and logograms lies in the history and development of iconography. Recognizing and comprehending a single sign is the simplest processing of reading in terms of iconographic communication. Iconographic communication (e.g., using signs, symbols, or icons to record and communicate information) is an important stage in early development of a formal writing system (Sassoon & Gaur, 1997). It is in the later stages that the relationship between writing and speech is tightened by the "phonetization" that enables symbolic expressions of objects and concepts correspond to exact categories of speaking sounds by the grapheme-phoneme correspondence (GPC) rules (Gelb, 1963). Because of this combination of visual and auditory input, a word or a logogram was born.

Icons and logograms (or logographical words) have etymological connections in the formal development of logographical languages. They are both visual representations of certain objects and concepts for communicating purposes. Reading a symbol or reading a word requires complex processes of decoding components of the presented stimulus for the purpose of deriving and/or constructing meaning in the brain. Such processes involve visual representations of information being perceived by the retina, processed by the visual cortex, and interpreted by various brain areas (e.g., Broca's and Wernicke's areas) that form a network related to language processing and semantic cognition.

"In the broadest sense, reading presumably entails basic sensory and motor component, as well as more central components, such as the analysis of visual word forms, the analysis of word sounds, and the analysis of word meaning (Fiez & Petersen, 1998, p. 914)." Presumably, reading symbolic information such as an icon demands more of our visual perception in the analysis of its graphics (Horton, 1994) and lacks the GPC rules to associate a sound with its visual forms. Superficially speaking, in spite of this difference in the analysis of phonology, both reading a word and reading an icon require semantic cognition of the brain in order to analyze the meaning that is associated with the visual representation. Since iconography has historical connections to written words, it is plausible to argue that single icon reading may share the same semantic system of language processing in the brain with single word reading.

Icons Are More than Just Pictures

To make a coherent argument of why single icon and word reading might share the same semantic system of language processing in the brain, before drawing a connection between icons and logograms, it is important to make a clear distinction between iconography and photography.

Horton (1994) defines a GUI icon as a small image that represents a program (or command), file, directory (also called a folder), or device (such as a hard disk or speaker) on computer displays. Modern GUIs often use icons to provide visual representations of a certain concept, object, activity, place, or event. Although in some cases, users can use a picture as an icon, most modern icons are designed symbols with a purpose to associate the symbolic illustration with a certain meaning. Unlike a photographic picture that "is worth a thousand words," an icon should not be open to a variety of interpretations but needs to represent a single meaning.

According to Abdullah and Hübner (2006), a designed visual representation of information such as an icon always has a communicative goal to achieve. By adapting Kapitzki's view, Abdullah and Hübner (2006, p. 11) classified eight different types of icons:

- Iconogram: a visual representation that emphasizes the points in common between a picture and a common object (e.g., an authentic line drawing of a building).
- Pictogram: a visual representation that illustrates complex facts, not through words or sounds but through visual carriers of meaning (e.g., International System of Typographic Picture Education (ISOTYPE); international traffic signs; and to some extent a form of written symbols such as those in hieroglyphic writing). Abdullah and Hübner have a high standard about designing a pictogram. A modern design of such an icon must achieve immediate visual realization of its

function. A pictogram must have characteristics of a sign according to definitions of semiotics that is attributed to Charles S. Peirce and Charles W. Morris (cf. 1938; 1946).

- Cartogram: a topographical representation with complex functions (e.g., statistics) and iconic facts (e.g., an atlas or the ground plan of a house).
- Diagram: a visual representation that is partly an iconic representation, but is more a functional carrier that illustrates sophisticated concepts (e.g., a chart of a sequence of mathematical facts or functions).
- Ideogram: a visual representation of a concept that corresponds to a symbol which relates to the object or concept referred to, independently of any formal identification with it (e.g., using an image of a floppy disk to suggest the action of saving data).
- Logogram: a visual representation that is a referential linguistic sign that does not take the phonetic dimension into consideration (e.g., unpronounceable acronyms in an alphabetical language). However, in logographical language, the definition of a logogram is different. A logographical word is a logogram with a phonetic element based on grapheme-phoneme correspondence (GPC) rules (Gelb 1963, p.54). To clarify and to fit in with Abdullah and Hübner's definition, in this dissertation, the term *logogram(s)* means logographical words (real words) of a logographical language and the term *pseudo logogram(s)* means logographical words that has no GPC references (a fake logographical word that cannot be pronounced).

- Typogram: a composed sign that is derived from a written repertoire such as the alphabet (e.g., company brand names like Google and Microsoft). Note that a nonword (pseudo word) that follows GPC rules in alphabetical languages can be classified in this category as well. This dissertation uses the term *nonword* or *pseudo word* to refer to fake alphabetic words that still can be pronounced.
- Phonogram: Phonetic representation that is used to signify linguistic or other sounds (e.g., a music note).

Alternatively, Wang et al.'s (2007) paper of icon taxonomy suggested that there were at least five types of modern GUI icons according to their functions and forms although the terminologies used to classify them might vary across literatures:

- Type 1 (terminologies: resemblance, similar, nomic, representational, pictorial, purely pictographic, concrete, or associative-literal): Icons that are typical, simple pictures of familiar objects or operations (e.g., using a picture of a coffee cup to represent a coffee cup).
- Type 2 (terminologies: examplar, example, metonymic mapping, or associative-abstract): Icons that use a typical object to present a general class of objects (e.g., using a coffee cup to refer to all cups).
- Type 3 (terminologies: symbolic, structure-mapping, or semi-abstract): Icons that are composed of geometric shapes and other non recognizable figures (e.g., using a cup-like shape or cutout to represent a cup).
- Type 4 (terminologies: mixed or associative): Icons that are composed of both representational and abstract images (e.g., inhibition traffic signs like "no trucks allowed" that combines a truck symbol and an inhibition symbol together).

- Type 5 (terminologies: arbitrary, abstract, or purely symbolic): Icons that have no intuitive connection between the icon and its referent (e.g., biohazard, radiation or peace signs).

As Wang et al. (2007) indicated—making a precise and consistent classification of icon taxonomy was impossible because differences existed in researcher's inclusion criteria and the playfulness of icon design. Nevertheless, Wang et al. (2007) concluded that, "A *concrete icon* is an icon that only depicts physical items that exist in the real world such as file or scissors. Conversely an *abstract icon* only depicts arbitrary elements such as metaphysical arrows, shapes and arbitrary symbols. An abstract icon does not allow text in any form and needs learning to be understood as its meaning is assigned. … A *combination icon* is best described as a fusion of a concrete icon and an abstract icon in that it depicts both items that exit in the real world and arbitrary elements" (p. 206).

An icon in most cases is not restricted to a purely pictorial representation of physical items in the real world. Besides representing physical objects in the real world, icons are also designed to represent concepts in indicative, imperative, and suggestive manners that convey certain meanings and instructions that require actions and behavioral responses of the reader (Abdullah & Hübner, 2006).

Since pictorial resemblance of objects is only one type of iconic representation, single icon reading should not be regarded equal to visual object identification. In fact, a recent fMRI study by Shin et al. (2008) has offered supporting evidence suggesting a distinct opposite pattern of response for the perception of icons versus pictures of actual objects by comparing neuroimaging data of icons and pictures of faces and houses. Yet, the remaining question is: if icons are not pictures in terms of their forms and functions, what are they and how should we best describe them in terms of how people read them?

Icons Can be Regarded as Logograms

If icons are not pictures, what are they? If it is plausible that people do not perceive and recognize icons as pictures, what is the alternative or analogical explanation? People might read icons as logograms because there is an etymological connection between these two visual representations of information.

The connection between icons and words dates back to the time when the logographical writing systems (e.g., Egyptian hieroglyphics that uses small and symbolic images to represent words) were used in ancient Aztec, Chinese, Egyptian, and Mayan cultures. Ancient forms of writing like iconographic symbols were found in the pre-historical cave-drawings and records of ancient religious practices such as the earliest animal painting found in the Lascaux caves in France, ca. 30,000-8,000 BCE and the Chinese oracle bone script, ca. 1,500-1,050 BCE that was directly ancestral to the modern Chinese characters (cf. Gelb, 1963; Sassoon & Gaur, 1997).

Like how ancient logograms are used, modern GUIs use icons to provide visual representations of a certain concept, object, activity, place, or event by symbolic illustrations in the computing environment (Sassoon & Gaur 1997). Iconic representations have become popular since the first GUI was developed at Xerox PARC in 1979 and later embraced by mainstream software development companies such as Microsoft and Apple (Caplin, 2001).

Haramundanis (1996) stated, “An icon is like a logogram, the type of object that was created as the start of the development of writing” (p. 2). This argument can be supported by the formal development of writing that can be seen in hieroglyphics and Chinese. For example, a simplified demotic logogram is evolved from a more detailed hieroglyphic drawing. A similar development of simplification can also be observed between the Chinese oracle bone script and the modern Chinese characters (Gelb, 1963).

The common ground of icons and logograms is the purpose of creating systematic symbols for reliable communication. According to Horton (1994), “you can use an icon anywhere you would use a word label” (p. 3), which suggests the interchangeability in function between icons and texts. Roughly speaking, logographical writing has two categories of logograms in terms of their linguistic attributes. One is of drawings that represent objects (pictographs), and the other is of drawings that represent a concept suggested by it (ideographs). Depending on the use of the word, the same logogram can fall into either category of pictographs or ideographs. For example, the use of word “sun” in Chinese can represent “day” as well. Today's computer icons share many similarities with logograms’ principles of representing objects and ideas (Caplin, 2001). For instance, the “save” icon, which is frequently symbolized with an iconogram of a floppy disk, shows an example of using an ideogram to suggest an operational action.

Chinese characters are logograms that are still actively used by many people today. It is the only logographical writing system that still has native speakers and does not have to be deciphered in modern times (Gelb 1963, p. 85). Like icon taxonomy that is reviewed in the previous section, there are different types of Chinese characters. According to traditional Chinese lexicography, 六書 (*liù shū*, “The Six Scripts”) and 說文解字 (*Shuō wén Jiě zì*, “The Explanation of Writing and Analysis of Words”), there are six categories of Chinese logograms according to the sample list of 9,353 characters under 540 radical entries (cf. Boltz, 1994, p.143-144; Hopkins, 1954, p.17-22; Liu, 1969, p.10):

- Pictographs (象形: *xiàng xíng*, “representing the form”): Of 9,353 Chinese characters according to *Shuō wén Jiě zì*, 364 of them are pictographs—stylized drawings that resemble the objects they represent. These logograms are generally among the oldest characters that are direct descendents evolved from oracle bone scripts (e.g., elements of the universe like sun 日, moon 月, mountain 山, water 水, tree 木, and rice 米; architectural structure like door 門, well 井, and farm 田; human body like eye目, ear 耳, and hand 手; and animals like cattle 牛, goat 羊, horse 馬, tiger 虎, bird 鳥, tortoise 龜, and fish 魚).
- Simple ideographs (指事: *zhǐ shì*, "indicating the matter"): Ideographic characters are the fewest: only 125 are counted among the 9,353. An ideograph expresses an abstract idea through a symbolic form, including adding symbolic modifications of pictographs to indicate a certain part of an item (e.g., the original character of “up 上” is a logogram of a dot above a horizontal line and “down 下” is originally a dot below a horizontal line; “blade 刃” uses a dot to indicate the part of a “knife 刀”; and “root 本” indicates that part of “tree 木” with an extra stroke at the base).
- Ideographic compounds (會意: *huì yì*, "joined meaning"): These 1,167 characters are the second largest group in Chinese logograms. They are also called *associative compounds* or *logical aggregates.* In ideographic compounds, two or more pictographs or ideographs are combined to suggest a third meaning (e.g., “good 好” is a “woman 女” with a “child 子”; “forest 森” is three “tree(s) 木”; “stuck 卡” is a combination of “up 上” and “down 下” that suggests the situation; and a “man 人” leaning against a “tree 木” is “rest 休”).

- Picto-phonetic compounds (形聲: *xíng shēng*, "form and sound"): These are often called radical-phonetic characters. They form the majority of Chinese characters—over 80 percent (7,697 in 9,353), and were created by combining a determinative with a rebus. A determinative (the semantic element, a "radical" that is used to organize characters in Chinese dictionaries) is a special class with limited numbers of Chinese logograms which supplies an element of meaning for the picto-phonetic compound (e.g., most characters related to femininity have the character "woman 女" as the radical such as "mom 媽" and "bride 嫁", and this rule of using determinatives also applies to ideographic compounds). A rebus (the phonetic element, similar to a phonetic complement) is a character within the picto-phonetic compound that approximately provides the correct pronunciation of the logogram (e.g., the pronunciation of "mom 媽" is close to "馬" and "bride 嫁" is close to "家"). Such compounds remedied the difficulty of using iconic forms to represent physically similar objects, actions, and abstract notions, without creating undue homophony as simple rebuses would (e.g., logograms of "dog 狗" and "wolf 狼" have the same radical "犭" but different rebuses in their word forms. They have different pronunciations according to their rebuses "句" and "良". Hence, it suggests that they represent physically similar but different types of animals).
- Phonetic borrowed characters (假借: *jiǎjiè*, "loaned and borrowed; making use of"): These are characters that are "borrowed" to write another homophonous or near-homophonous morpheme, comparable with using "4" as a rebus for English

"for." These “loaned and borrowed characters” often lost their connections to the original meanings through time; thus, in most cases, new characters were created to replace them for meanings that these loaned and borrowed characters originally represented (e.g., the character “come 來” was originally created to represent “wheat” but it was borrowed to be used as a verb so a new character was created to represent “wheat 麥”).

- Mutual lexicography (轉注: *zhuǎn zhù*, "turn to explain"): This classification is of purely historical value, and is the least understood of the *liù shū* principles of character formation. It may refer to characters which have similar meanings and often the same etymological root, but later have diverged in pronunciation and meaning in common use (e.g., the character “test 考” shares the same etymology with the character “old 老”, but is commonly used to mean “test” in modern times).

If excluding phonetic borrowed characters and mutual lexicography of Chinese logograms (since these two categories are more associated with the logogram’s etymological development and usage instead of being about the logogram’s forms and linguistic attributes), the functions and linguistic attributes of the first four categories of Chinese characters share great similarities with the functional taxonomy of modern icons suggested by Abdullah & Hübner (2006) and Wang et al. (2007). Analogically, iconograms and concrete icons are like Chinese pictographs; ideograms and abstract icons are like Chinese ideographs; and pictograms or combination icons are like Chinese ideographic compounds. Note that most icons do not have phonetic elements embedded within symbols like Chinese picto-phonetic compounds. Loosely speaking, a combination icon has attributes of a phonogram (e.g., music notes) or a textual label is like a Chinese picto-phonetic compound.

The analogical similarities in GUI icons and Chinese characters provide a rational argument to hypothesize that icons are logograms. Based on such an argument, Haramundanis (1996) suggested that designing icons should be like creating words for a logographical language system.

Discourses between Haramundanis (1996) and Pedell (1996) about icon independence suggested that a novel icon could stand alone only if the user had learned the meaning of it and had been familiar with its designated function via textual labels and repeated interactions. Haramundanis (1996) suggested that recognizing stand-alone icons was like reading logograms. Learning the meaning of an unfamiliar icon was like learning how to use a new word, which could be mastered by reinforced and constant exposure to improve the efficiency of user performance (Wiedenbeck, 1999).

Early discourses of icon independence (cf. Haramundanis, 1996; Pedell, 1996) and studies of learning and retention of using icons in GUI menus (Wiedenbeck, 1999) suggested that people might read icons and logograms in the same behavioral and cognitive manner. Therefore, the question that follows the hypothesis of icons being logograms is: do people read icons like they read logographical words? In other words, do icons influence people's behaviors and cognitions in the same way as logograms?

Pragmatic Interactions: How Icons Affect Behaviors and Cognition

Icons in HCI Research about End-users' Behaviors and Cognition

Retrospectively, studies of HCI introduced principles of human-factors research into software engineering to understand how people perform in various computing environments. An early, influential example was the model of Goals, Operators, Methods and Selection (GOMS) rules that emphasized human beings' cognitive structures underlying manifest behaviors of HCI (Card et al., 1983). The GOMS model is an application of cognitive psychology and it mainly concerns how perceived stimuli in a computing environment are cognitively processed by the human user and consequently trigger his/her behavioral responses. It also concerns how well the human user performs under the influences of computing stimuli in terms of efficiency and accuracy. The effect of icons, as a very important component of interactions in GUIs, is a significant subject of research under the discipline of human-factors modeling that has flourished since the GOMS model was introduced.

The first commercial introduction of GUIs in 1984 generated a lot of discourses about differences in user performance between command line interfaces and GUIs. In these studies, icons and text labels were often used as independent variables in menu selection or information retrieval (IR) tasks to investigate how quickly and accurately end-users could complete such tasks. A representative example was Wiedenbeck's study (1999) about the use of icons and labels in menu selection. Wiedenbeck tested three types of menu including an icon-only interface, a text-only interface, and an icon-text interface. She found that there was no significant difference in user performance in terms of speed between the icon-only interface and the text-only interface, but participants performed significantly faster with the icon-text interface in contrast to the other two interfaces.

The combination of well-designed icons and appropriate labels has become a standard guideline in the interface design community today, but there are rarely discourses about why icons cannot outperform texts or vice versa in terms of how people process them. Instead, researches following Wiedenbeck's study split into two major directions: one focuses on finding representational factors that affect the effectiveness of icon design for human icon processing, and the other focuses on identifying end-user differences that affect universal icon interpretation. Nevertheless, these two directions of research are still on the subject about how icons affect people's behavioral and cognitive performance.

Factors in Icon Design that Affect Human Icon Processing

The end-user's behavioral and cognitive performance in human icon processing is influenced by design factors such as icons' concreteness, complexity, distinctiveness, guessability, and learnability (cf. McDougall et al., 2000 and Moyes & Jordan, 1993). These design factors are often determined by visual variables of an iconic representation. There are many visual variables (i.e., orientation, metaphorical diversity, relative position, size, color, resolution, and labeling) that can make an iconic representation of the same item or concept different. Many studies have reported that the effects of these variables will influence outcomes and performance of user-system interactions.

Kamba et al.'s (1996) study on widget arrangement and Wang et al.'s (2006) study on visual information piles showed that careful optimization of icons and text was a critical factor to use small screen space more efficiently to present information content for user interactions. Moyes (1994) found that the position of an icon was more important than the shape of an icon for the user to recognize it in a GUI menu. Chu et al. (1999) suggested that 5 x 5 mm is the smallest size at which an icon can be recognized with details of its graphical elements. For the best outcome in visual perception, Kurniawan (2000) suggested that in designing an icon, the designer should not use more than nine hues and a four-bit color scale for its color scheme. In addition, for an individual icon to be physically distinctive based on the rules of human visual acuity and contract sensitivity, Kurniawan (2000) suggested that the minimum size of the finest detail cannot be less than 0.873 mm, which sets the limitation of an icon's resolution. Lindberg and Näsänen (2003) discovered that icons' sizes and the spacing between them would affect the speed of users' visual search. Similarly, Everett and Byrne's (2004) study identified effects of icon spacing that might change users' visual search strategies.

Although many effects of visual variables of an icon have been identified, the representational issue of icon design is not a simple question of good or bad manipulations of visual presentations (Huang & Bias 2011). Specifically, when two visual presentations are interchangeably good or ambiguous for the same object or concept, when first encountering these icons, how do end users make a decision regarding their meanings if they do not have access to their text definitions?

In addition, adding an additional graphic element to an icon will change its taxonomy (Wang et al., 2007) and meaning in design (Setlur et al., 2005) at the same time. Unfortunately, there is never a direct quantitative measure of an icon's meaningfulness other than tools of evaluating its visual complexity (e.g., Forsythe, 2003 and Byrne, 1993), detectability, and interpretability (e.g., Webb et al., 1989 and Barr et al., 2003) in contrast to other icons in similar designs. The answer is never absolute and objective, but comparative or subjective. Representational factors of icon design further indicate the challenge of conveying a stable context via icons because a graphical representation of an object or a concept might signify more than one meaning (cf. Haramundanis, 1996 and Pedell, 1996). Such an issue will greatly affect how people can efficiently and accurately read and interpret icons.

End-user Differences that Affect Icon Interpretation

Designers will always face the challenge of putting propositional meanings into icons (cf. Abdullah & Hübner, 2006; Barr et al., 2003; Ferreira et al., 2005, 2006; Mitsock, 1994, and

Payne & Starren, 2006). Even though system designers have addressed the representational issue by achieving the optimal presentation of visual elements of an icon, they still need to deal with the issue of how end users will use and interpret it.

When an icon is created, the designer will assign one official label that defines its functional or operational meaning. Having access to an icon's text definition will at least minimize the possibility of a user's unexpected interpretations of linguistic and non-linguistic expressions of an image that lead to incorrect interactions with the system. Therefore, when the user is using an icon, the user is building the lexical access of a certain icon to a certain signified text that is a noun, a verb or a short phrase that is suggested by the label, in the brain. Although this assumption does not yield the possibility that an icon can still be interpreted differently by the user, the designer inevitably needs to assume that through learning and retention activities, users can establish efficient connections between icons and their designed meanings (cf. Goonetilleke et al., 2001 and Wiedenbeck, 1999).

Despite the fact that users can learn to efficiently and effectively use certain icons and be familiar with their contextual meanings through times of exposure or training (cf. Goldberg et al., 2008, Goonetilleke et al., 2001 and Kunnath et al., 2005), this fact does not ultimately solve the issue that people might have different interpretations of the icon from its designated meaning. In fact, creating an icon that, without explanation, communicates an absolute concept across cultures is very difficult. Studies of Walton et al. (2002), Kim and Lee (2005), McDougall et al. (2005), Wang (2007), and Schröder and Ziefle (2008) showed that factors of visual literacy, culture differences, age differences, and language efficiency of end users all contributed to challenges and obstacles in the internationalization of interfaces and universal icon recognition or interpretation.

Many cultural symbols are well perceived because of many years of reinforcement so that people who are familiar with them can immediately recognize them without accompanying text or other explanation (Watzman & Re, 2008). For example, putting a skull symbol on a bottle is well perceived as poisonous or deadly substance in many cultures because the symbol is often associated with death. Another instance is that the Nazi symbol and the swastika symbol are the same, but they represent different contexts for different groups of people in different places and periods of time.

The possibility of different interpretations of the same symbol raises the concern that every graphical representation does not necessarily have a consistent and transcending meaning. Unfortunately, the current resolution to such a challenge focuses only on developing design criteria that people will perceive and use icons more effectively and efficiently (cf. Barr et al., 2003 and Hemenway, 1982). Such studies that focus on identifying design factors of icons and individual differences of end-users might have found keys to improve behavioral performance of human icon processing, but the knowledge about how human cognition works to interpret icons remains mostly elusive.

Toward a Neuroergonomic Understanding

Understanding how human cognition works to interpret icons is not easy. Although there are studies like McDougall and Curry's (2004) framework of icon interpretation from a cognitive psychological perspective or Yu and He's (2010) analysis of users' cognitive factors toward icons, most similar articles lack empirical evidence to support their theoretical discussions about the mechanism of cognition in human icon processing.

HCI research of human icon processing mostly follows the paradigm of behavioral methods in cognitive psychology (cf. McDougall et al., 1999, 2000, 2001, 2004, 2005 and

Isherwood et al., 2007). Using the paradigm of behavioral methods in HCI research has been a long tradition. Early approaches such as the GOMS model and the human information processor model (or model human processor, MHP) are examples of modeling human abilities and cognitive processes in HCI, which allow for different aspects of an interface and user responses to be studied and accurately predicted (Card et al., 1983). However, behavioral methods have limitations in understanding the mechanisms of human cognition underlying physical responses. Beyond behavioral modeling of the efficiency and accuracy of end-users' physical responses, HCI researchers recently have been adapting new methods to study how human cognition works to process different stimuli provided by machine interfaces in various computing environments. For instance, studies applying analyses of event-related potentials (ERPs) to HCI have shown the potential of using neuroimaging methods to understand human factors such as fatigue, depletion and attention of cognitive resources during HCI tasks (e.g., Trimmel & Huber, 1998). These findings have demonstrated great potential for using neuroimaging methods to evaluate aspects of HCIs that conventional behavioral testing tools cannot probe into.

Application of cognitive neuroscience to HCI has been advocated under the heading of neuroergonomics. According to Parasuraman (2003), "Neuroergonomics focuses on investigations of the neural bases of mental functions and physical performance in relation to technology, work, leisure, transportation, health care and other settings in the real world" (p. 5). The goal of neuroergonomics is to use knowledge of the relation between brain function and human performance to design interfaces and computerized systems that are sensitive to brain function with the intent of increasing the efficiency and safety of human-machine systems (Proctor & Vu, 2008). By this neuroergonomic approach, a better understanding of how humans establish the connections between representations of the information system and their contextual meanings seems more promising than before.

Some might question why it is necessary to investigate brain functions to understand how people produce semantics (meanings) of perceived stimuli. A distinctive reason is that human brains have the unique capability of creating contextual meanings during interactions with information perceived in a given environment. Even with all of our advances in technology, this special ability is still exclusive to humans and cannot be duplicated by current artificial devices (Freeman, 2000, 2002). The question of how humans create meanings remains mostly unexplored territory. Moreover, an objective and accurate measure of meanings is shown to be an improbable application of mathematic precision (Klir & Wierman, 1999). It is seemingly impossible to explain the origin of semantic production except via probing into the neural mechanisms of the brain with neuroimaging methods.

Interpreting the meaning of presented stimuli is essentially a cognitive process of the brain. It is practical to take the neuroergonomic approach to investigate how human icon processing works and whether people do read icons as logograms because of their epistemological connections. Consequently, the following section is devoted to reviewing the brain's neural mechanisms of language processing and the brain's semantic system to understand semantic productions of icons and texts.

Semantic Productions: How the Brain Generates Meanings from Icons

Like words, an icon as a semiotic sign can also be read and comprehended. Reading is a cognitive process underlying neural mechanisms of the brain. To determine if icons are read as logograms, one methodology in neuroscience is to compare neural representations of single icon and word processing in the brain. If neural representations of single icon processing share the same network and brain regions with single word processing, they will provide evidence to support the proposition that people do perceive and comprehend icons as logograms. The following sections review the neural representations of single word processing and use them as references to draw connections to single icon processing. The neural representations of single word processing include: 1) the language processing network, and 2) the semantic system underlying language processing of the brain.

Language Processing and the Semantic System in the Brain

Early studies of language disorders in aphasia patients provided two important discoveries of language-related areas in the human brain. One suggested that language processing depended principally on the left hemisphere in the majority of healthy individuals, especially right-handed people (Knecht et al., 2000). The other suggested that two cortical areas on the left hemisphere, the lateral frontal region (Broca's area) and the posterior superior temporal lobe (Wernicke's area), served critical roles in speech generation and language comprehension (Kandel et al., 2000).

These findings in aphasias helped develop the Wernicke-Geschwind model of language processing (Figure 2.1A). This classic model suggests that adjacent regions of Broca's and Wernicke's area participate to form a complex network. For example, the motor cortex (Precentral gyrus) controls the movements of facial expression, articulation and phonation. The angular gyrus (AG) and the superior temporal gyrus (STG) are part of the language network joined by the arcuate fasciculus, which is a bidirectional pathway that connects Broca's and Wernicke's area.

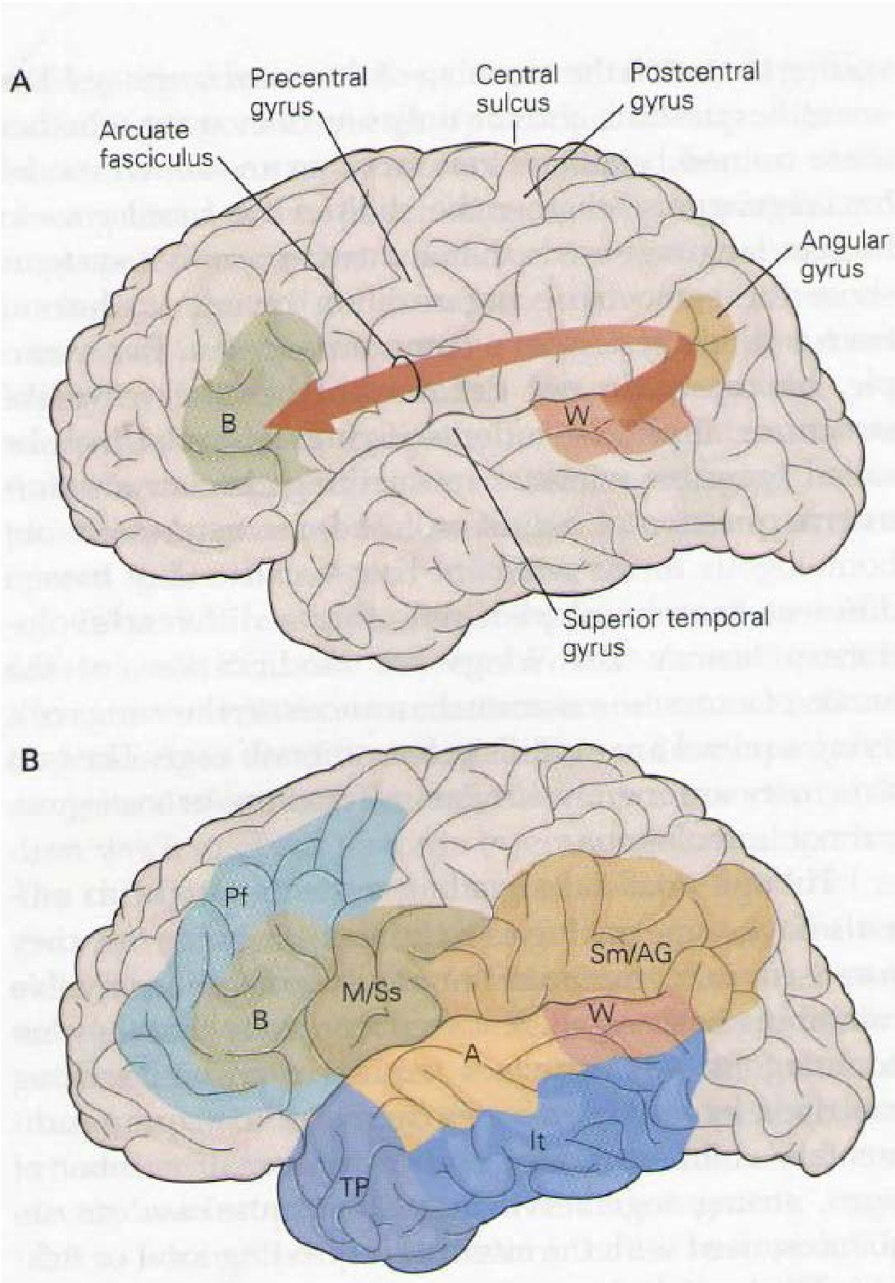

Figure 2.1 The Classic Model versus the Modern Framework of Language Representations in the Brain (Kandel et al., 2000, p. 1174)

Based on the Wernicke-Geschwind model, psycholinguists and experimental neuropsychologists later developed a more elaborate view of the language areas in the left hemisphere. This modern framework is more complicated and includes 1) the left frontal, temporal and parietal regions involved in connecting semantic concepts and language processing; 2) cortexes of the left insula and Heschl's gyrus that are related to speech articulation; and 3) prefrontal and cingulate areas that implement working memory and attention (cf. Démonet et al., 2005 and Kandel et al., 2000). Unlike the simpler class model that has only two major language areas, the modern framework suggests that the language network contains three systems in the brain: the implementation system, the mediational system and the conceptual system (Figure 2.1B).

The implementation system is constituted by regions around the left lateral (sylvian) fissure: Wernicke's area, supramarginal gyrus, angular gyrus, auditory cortex, selected areas of insula, the left basal ganglia complex, motor cortex, somatosensory cortex, and Broca's area. In addition, Wernicke's area and Broca's area are interconnected by the arcuate fasciculus forming the bidirectional pathway between the posterior and anterior components of the implementation system. This system is involved in processes such as analyzing auditory signals, activating conceptual knowledge, ensuring phonemic and grammatical construction and conducting articulatory control. The implementation system is surrounded by the mediational system made up of the left temporal pole, left inferotemporal cortex and left prefrontal cortex. This secondary system acts as an agent between the implementation system and the conceptual system, which includes the remainder of higher-order association cortexes supporting conceptual knowledge that is linking to language (Kandel et al., 2000).

This modern framework covers almost the entire left hemisphere and suggests that the language processing network dominates the major reigon of semantic cognition in the brain including sensory and motor related cortexes (Figure 2.2). This language processing network is so vast that we can assume that any word-related form of visually represented information would be processed by it. The problem is how these cortexes are bound to give meaning of the visually represented information.

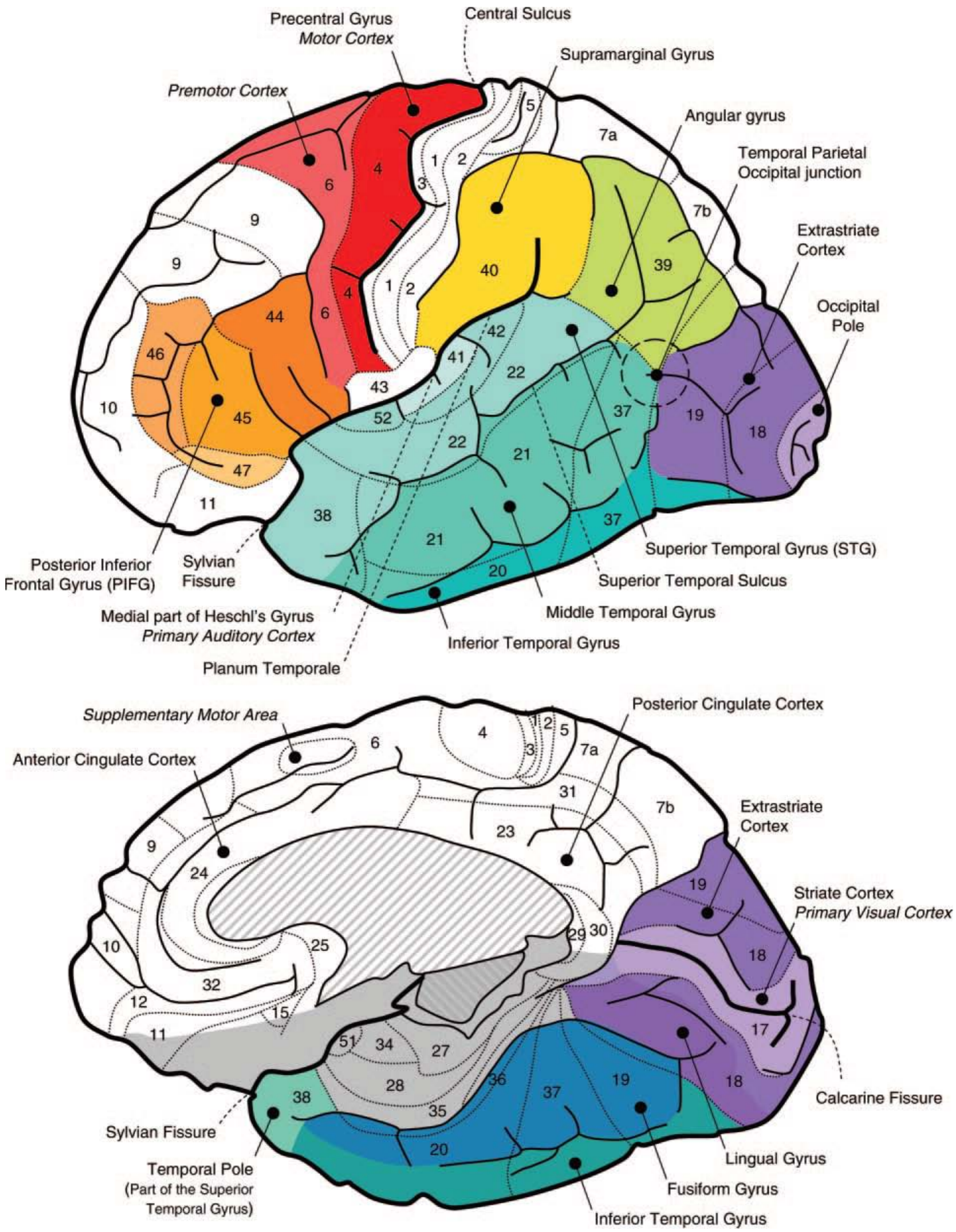

Figure 2.2 Brain regions involved in language processing (Démonet et al., 2005, p.63)

Modern language scripts have evolved from ancient iconographic symbols. The brain must have processing systems that resolve problems about decoding visual representations of information before it deals with language stimuli. It is plausible that such a semantic system that deals with symbolic information is also responsible for language processing of written words.

Studies of visual perceptions have identified categories of neurons in the primary visual cortex that respond best to specific orientations (cf., Hubel & Wiesel, 1959; Zeki, 1993). For instance, certain neurons respond best to a vertical bar of light and are less or not sensitive to a bar that has different orientation. Knowing the brain has such organizations (hypercolumns) of neurons is a breakthrough in understanding the neural mechanisms of object recognition. This knowledge confirms that an object can be perceived and decoded by orientation representations in the brain. Tanaka (1993) conducted a similar object recognition study about neurons in the anterior inferotemporal cortex (TE area) of the macaque's brain. His study also suggests that an object's critical features are possibly represented by the activity of clusters of multiple neurons within a single columnar module. This single columnar module works selectively to absorb the changes like illumination, viewing angle and articulation of the object. These studies of visual perceptions have indicated that the brain has the ability to decode visual representations of information.

Semantic cognition research aims to understand cognitive processes that access stored knowledge about the world. Such semantic knowledge "is about objects and their properties, and of relationships between and among them, including knowledge of word meanings (McClelland & Rogers, 2003)." It is generally believed that neural representations of semantic processing are widely distributed in the brain. Object recognition and word recognition are two major categories of semantic cognition research. However, there is a clear dichotomy between using scenery pictures (representations of objects) and using words as stimuli in semantic cognition research among neuroimaging studies.

For example, in Binder et al.'s (2009) review of 120 studies regarding the cortical representation of the semantic system about language processing in the brain, they applied selective criteria that excluded studies that emphasize using object pictures to elicit knowledge retrieval. Their inclusive criteria were based on the argument stating that object recognition and word recognition elicit semantic access routes that were not identical. Binder et al. (2009) claimed that 1) "object recognition engages a complex, hierarchical perceptual stream that encodes progressively more abstract representations of object features and their spatial relationships" (p. 2), and 2) comprehension of a word did not entail activation of a detailed perceptual representation of the object to which it referred—literate people do not need to see a picture of a cup to understand the meaning of the word "cup." Evidence enlisted by Binder et al. (2009) included neuroimaging studies regarding 1) different activation patterns during matched word and picture recognition tasks, and 2) patients who had selective impairments between visual object recognition and word comprehension. Such evidence argued against a complete overlap between the knowledge systems underlying object and word recognition.

Although there is a clear dichotomy between using object pictures and using words as stimuli in semantic cognition research, icons are somewhat in an ambiguous place between these two types of stimuli. The main purpose of this dissertation is to test the hypothesis that people read icons as logographical words instead of as pictures. The author is taking a proposition that suggests the same semantic system of language processing is also involved in icon recognition. Thus, Binder et al.'s (2009) review on the semantic system that processes word stimuli and correspondent tasks can provide fundamental knowledge about possible semantic contracts that might be activated by iconic stimuli as well.

Binder et al.'s (2009) meta-analysis of 120 functional neuroimaging studies about semantic contrasts included 1) words versus pseudowords, 2) semantic task versus phonological task, and 3) high versus low meaningfulness. According to these studies, about 68 percent of the activation foci are in the left hemisphere and 32 percent in the right hemisphere. This indicates the semantic system is widely distributed in the brain and has moderate lateralization in the left hemisphere (Figure 2.3).

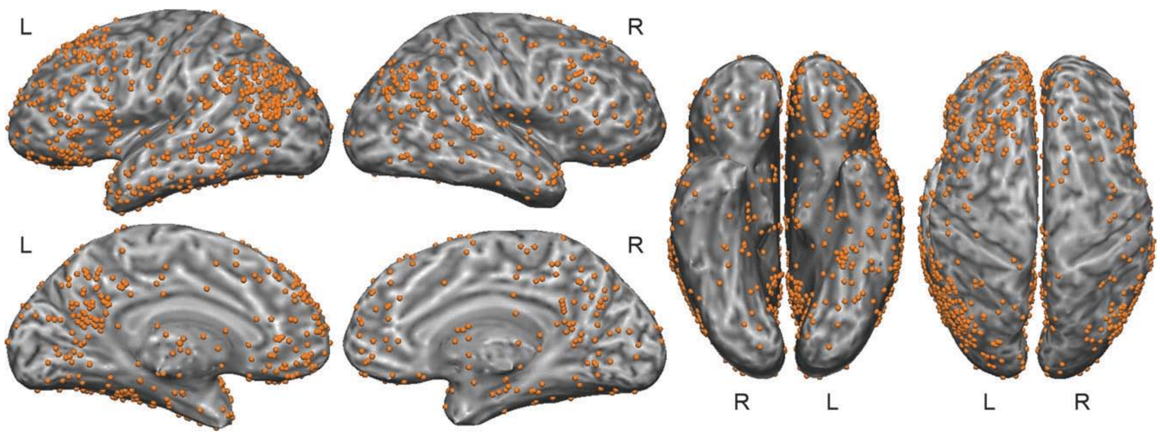

Figure 2.3 Activation Foci of Semantic Contrasts (Binder et al., 2009, p. 2)

Binder et al. (2009) identified seven principal regions of the large-scale semantic network of the human brain (Figure 2.4). These cortical areas are: 1) the angular gyrus (AG) and adjacent supramarginal gyrus (SMG); 2) the entire length of the middle temporal gyrus (MTG) and posterior portions of the inferior temporal gyrus (ITG); 3) a ventromedial region of the temporal lobe centered on the mid-fusiform gyrus and adjacent parahippocampus; 4) dorsomedial prefrontal cortex (DMPFC) in the superior frontal gyrus and adjacent middle frontal gyrus (MFG); 5) the inferior frontal gyrus (IFG), especially the pars orbitalis; 6) ventromedial prefrontal cortex (VMPFC) and orbital prefrontal cortex, and 7) the posterior cingulate gyrus and adjacent ventral precuneus.

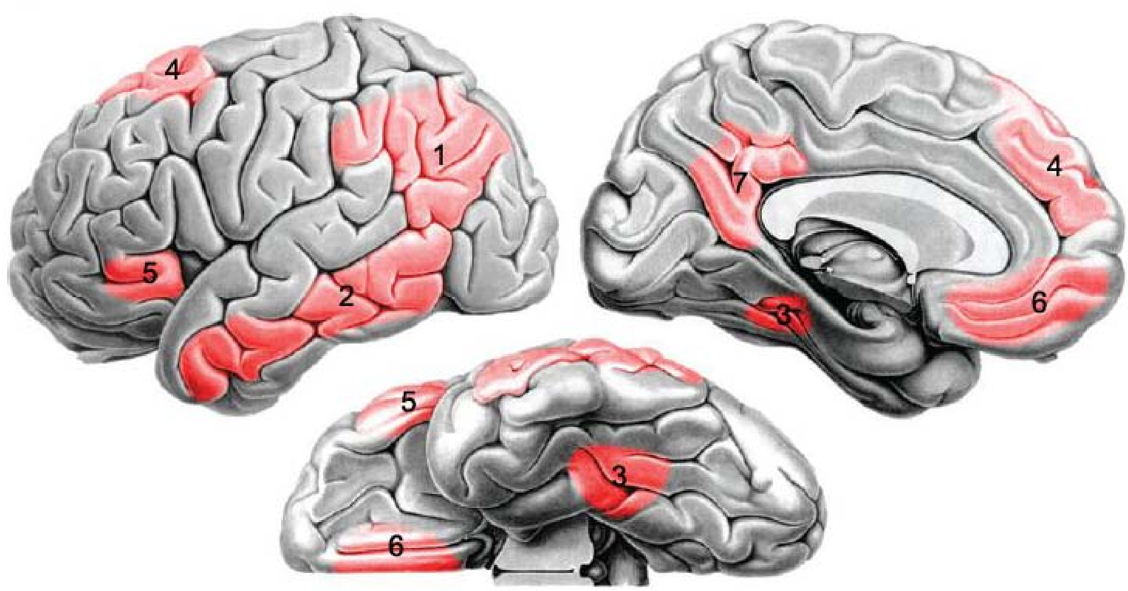

Figure 2.4 Principal Regions of the Semantic Network in the Human Brain (adapted and modified from Binder et al., 2009, p.13)

By summarizing empirical data of their meta-analysis, Binder et al. (2009) proposed underlying functions of these seven principle regions that manifest essential roles in semantic cognition. The AG is anatomically connected almost entirely with other association regions and receives little or no direct input from primary sensory areas. The AG likely plays a role in complex information integration and knowledge retrieval such as sentence comprehension, discourse, problem solving, and planning.

The MTG, the ITG, the fusiform gyrus, and the parahippocampus in lateral and ventral temporal cortex are likely heteromodal cortex involved in supramodal integration and concept retrieval. The MTG and the ITG of the temporal lobe may be a principal site for storage of perceptual information about objects and their attributes (e.g., tools and their action concepts), whereas the superior temporal gyrus' (STG) role in language comprehension relates primarily to speech perception and phonological processing rather than to retrieval of word meaning.

Most studies of the fusiform and the parahippocampal gyri use object pictures as stimuli instead of words. However, these two areas are also important to language processing. The mid-fusiform gyrus plays a particular role in retrieving knowledge about the visual attributes of concrete objects. The parahippocampal component acts as an interface between lateral semantic memory and medial episodic memory networks.

The left DMPFC is adjacent to motivation and sustained attention networks (e.g., anterior cingulated gyrus, premotor cortex and supplementary motor area). If the left DMPFC is damaged, it will affect self-guided, goal-directed retrieval of semantic information. For example, patients having such a lesion can repeat words and name objects normally but cannot invent responses that are not formulaic according to preset procedures or instructions. The left IFG may affect the "efficiency" of semantic processing, but its functions are more related to phonological, working memory, and syntactic processes. The left VMPFC is implicated in many studies of motivation, emotion, and reward processing and it probably plays a central role in processing the affective significance of concepts (e.g., the emotional attributes of words). The posterior cingulated gyrus has been linked with episodic and visuospatial memory functions, emotion processing, spatial attention, and visual imagery. By virtue of its strong connections with the hippocampus, the posterior cingulated gyrus acts as an interface between the semantic retrieval and episodic encoding systems.

The semantic processing network proposed by Binder et al. (2009) supports the traditional distinction between conceptual and perceptual processes. Such a demarcation between activated brain areas of conceptual and perceptual processes is shown in Figure 2.5. Binder et al.

(2009) suggest that “conceptual processes operate on ‘internal’ sources of information (e.g., semantic and episodic memory) that can be retrieved and manipulated at any time and are independent of ongoing external events” (p. 16). On the other hand, “perceptual processes operate on ‘external’ information derived from immediate, ongoing sensory and motor processes (e.g., reading pseudowords aloud) that coordinate interactions with the external environment” (p. 16). Many tasks (e.g., recognizing a word or a picture) require simultaneous processing of both internal and external information, where “external sensory information is given meaning by activation of associated internal information.”

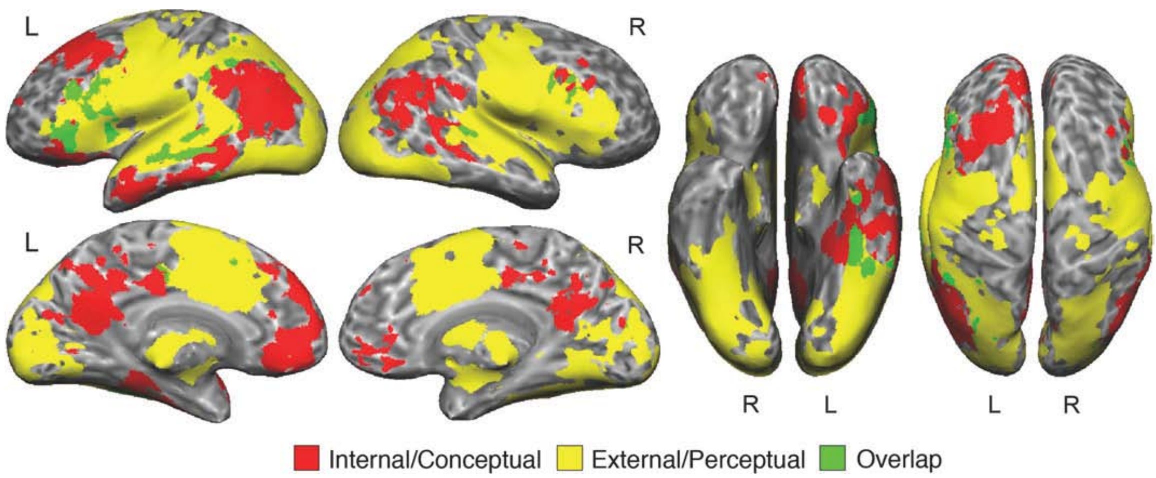

Figure 2.5 Conceptual versus perceptual processing (Binder et al., 2009, p. 17)

Neural Representations of Single Word Processing

Binder et al.’s (2009) review of the semantic system in the brain provides great insights about specific cortical regions underlying the semantic processing of word-related stimuli. In addition, this semantic network makes a general distinction between conceptual (red areas) and perceptual (yellow areas) systems in the brain (Figure 2.5). This mapping between conceptual and perceptual processing of word-related stimuli provides references that can be used in the comparison between single icon and word processing. Since this dissertation hypothesizes that icons are processed by the brain as logograms, fMRI data should show the same or similar patterns of activated cortical regions in conceptual processing of the semantic system (the red areas in Figure 2.5) during icon and word recognition tasks. However, whether the perceptual processing of icons would show the same or different patterns of fMRI data in the yellow areas is difficult to predict.

Unlike the conceptual processing that has been identified with seven principle regions in the brain, the neural representations of the perceptual processing of single word reading have not been well studied. The perceptual processing of single word and logogram processing includes two input modalities that provide access to the semantics: phonological processing and direct access (also called orthographical or logographical processing) (cf. Bias & McCusker, 1980; Bias et al., 1982; Foss & Hakes, 1978). On the other hand, unlike a logographical word that has a phonological component that allows the reader to connect a discrete image with a specific sound, an icon does not have an innate speech code but exhibits an utter logographical symbolism that is associated with a conceptual knowledge. Hence, single icon reading might have two routes that connect to semantics: one is via direct access and the other one is via lexical access. Single icon reading might be more weighted in direct access. According to the dual-route and connectionist model, there are “lexical” and “nonlexical” reading routes in single word processing where researchers have argued that reading comprehension is not exclusively reliant upon phonological representation (cf. Coltheart & Coltheart, 1997; Coltheart et al., 2001; Roberts et al., 2003). Simply put, direct access to semantics is also an important cognitive mechanism that is provoked by the word’s orthography/logography. Such a processing route in single word reading might be equivalent to visual decoding of single icon reading.

Although single icon processing might have equivalent input modalities as single word processing that provide access to semantics, neural representations of these two input modalities have not yet been clearly identified in neuroimaging studies (cf., Cohen et al., 2003; Démonet et al., 2005; Fiez & Petersen, 1998; Mechelli et al., 2003; Rumsey et al., 1997). Results of imaging studies about single word processing that aimed to locate brain areas associated with these input modalities "have not been entirely consistent, even at the level of reading single words" (Tagamets et al., 2000, p. 281). This weakened the reliability of comparing data across imaging studies of different experimental designs. In addition, it has been difficult to establish a precise and consistent analysis to see the dissociation of phonological and orthographical processing among neuroimaging data. Mechelli et al., (2003) suggested that such inconsistencies were due to limitations of selecting appropriate stimuli that can better stimulate or segregated sublexical processes of word recognition.

Given the current state of research findings about the perceptual processing of single icon and word reading, it is not reliable to predict that such patterns of fMRI data in the perceptual processing of single word and logogram reading will match those in single icon reading. For this reason, this dissertation will focus on the contrasts within the conceptual processing of the semantic system only to determine if reading icons is using the same language network that deals with words and logograms. Potential findings of differences in the perceptual processing of reading single icon and word will be discussed and posed as future studies.

Chinese, Photographic, and Phonetic Stimuli in fMRI Studies

Chinese native speakers are assumed to rely on the word forms rather than the word sounds of Chinese characters for semantic processing. Since Chinese characters evolved from simplified visual logos, several neuroimaging studies have been exploring the connections between Chinese character reading and picture naming (cf. Chee et al., 2000; Lee et al., 2004; Yoon et al., 2006).

It has been proposed that the logographical nature of Chinese characters has greater predictability in the mapping of the word form to its meaning, whereas the semantic mapping of English words is based on the process of phonology. Although it is a rational hypothesis that there may be a relatively large cognitive overlap between Chinese character identification and picture identification, many researchers argue that a great number of Chinese characters are discrete linguistic units including arbitrary symbols (radicals) that are neither pictographic nor alphabetic. This suggests that processing a character still will be more like language processing than picture processing for Chinese speakers. However, there are contradictory discourses in findings of neuroimaging studies about the relation between Chinese character reading and picture processing.

For example, character-picture comparisons revealed dependent differences in blood-oxygenation-level dependent (BOLD) contrasts between logograms and pictures in fMRI data (Chee et al., 2000). Findings of Chee et al. (2000) and Lee et al. (2004) about character-naming relative to control conditions (i.e., picture naming or English word reading) claim that: 1) semantic processing of Chinese characters shares greater similarities with English words than with pictures; 2) BOLD contrasts due to effects of Chinese characters are more strongly related to the phonological pathway than the ventral or visual object-recognition pathway, and 3) Chinese logogram-to-phonology transformations (as seen in brain activation patterns) are similar to orthography-to-phonology transformations of English word reading, which suggests the neural mechanisms for language processing are universal across different writing systems.

On the contrary, Yoon et al. (2006) argued that “more right hemispheric regions, except for the inferior frontal cortex, are involved in the reading of Chinese characters compared with English words” and “a right hemispheric dominance within the occipito-temporal and the left middle/medial frontal area for both reading Chinese characters and naming pictures" (p. 93). Yoon et al. (2006) suggested that such overlapping regions in the right hemisphere should not be overlooked and the data "should reflect the specific visual processing of reading Chinese characters" (p. 94).

Some studies tried to explore the differences between modulated neural activations of pictographic/ideographic logograms and phonetic logograms. For instance, studies of Sugishita et al. (1992) and Nakamura et al. (2002; 2005) about distinctions between Japanese Kanji (adapted Chinese characters) and Kana (Japanese alphabets) showed that: 1) the processing routes for these two types of words were not clearly separated and used largely the same cortical regions; 2) writing and subliminal priming of Kanji (presumed to be ideographic) and Kana (presumed to be phonographic) scripts modulated the visual occipito-temporal activations according to their graphic features, and 3) Kanji had slightly more mesial and right-predominant activation, whereas Kana had greater occipital activation.

Chen et al. (2002) conducted a similar testing for dual processing routes in reading by directly contrasting Chinese character and Pinyin (Chinese alphabetic sound symbols based on the Romanization system) reading, and suggested that: 1) reading Chinese characters and Pinyin activated a common brain network including the inferior frontal, middle, and inferior temporal gyri, the inferior and superior parietal lobules, and the extrastriate area; 2) reading Pinyin led to a greater activation in the inferior parietal cortex bilaterally, the precuneus, and the anterior middle temporal gyrus; and 3) reading Chinese led to greater activation in the left fusiform gyrus, the bilateral cuneus, the posterior middle temporal, the right inferior frontal gyrus, and the bilateral superior frontal gyrus.

Findings of Chen et al. (2002) and Yoon et al. (2006) seemed to suggest that reading Chinese was different from reading English because single word processing in Chinese involved greater modulated activations in bilateral and right hemispheric regions and required a larger extent of the semantic system in the brain. Their findings concurred with Binder et al.'s (2009) review indicating that the activation foci of language processing were widely distributed in both hemispheres. In addition, reading Chinese activated regions that were more associated with the ventral pathway of visual word processing in the left hemisphere, whereas reading English modulated greater activation in the dorsal pathway of phonological processing in the language network. On the other hand, the relation between Chinese character reading and picture naming is opposite to the relation between Chinese character reading and English word reading. Chee et al. (2000) argued that access to meaning for Chinese characters involved obligatory phonological processing in left middle and superior temporal gyri as in English words, whereas picture naming happened after semantic accessing and had a predominantly right occipital effect that was not specifically related to reading words. Therefore, Chinese characters were processed more like English words and not processed as pictures.

As previous studies indicated, the processing of Chinese logograms, English words and pictures shared the same semantic system that covered both hemispheres and their differences in the perceptual processing were identified by contrasting each condition's modulated activations of fMRI data. This dissertation will use the same contrasting method to determine if the brain processes icons as logograms instead of pictures.

Limitations of Comparing Different Visual Stimuli in fMRI Studies

The cultural differences between language groups might influence the cognitive processes of different languages. Although it is assumed that language processing is a universal mechanism in human cognition across cultures, results of language-related neuroimaging experiments might be biased by factors that are subject specific (e.g., gender, age, handedness and literacy) and language specific (e.g., phonemes, metaphors, lexicality, categorization and frequency) (Démonet et al., 2005). These factors need to be controlled in the experimental design.

Most fMRI studies were about language processing in English and many of them used word-nonword comparisons as the experimental paradigm. The same or similar experimental paradigm was also implemented in studies about cognitive processes of logographical languages such as Chinese and Japanese (cf. Binder et al., 2009; Chee et al., 2000; Cohen et al., 2003; Démonet et al., 2005; Fiez & Petersen, 1998; Lee et al., 2004; Mechelli et al., 2003; Rumsey et al., 1997; Yoon et al., 2006). However, there were several limitations in these neuroimaging studies that used word-nonword comparisons to investigate cognitive processes of logographical languages. Firstly, other than manipulating words to create different reading conditions, past studies did not recognize the potential of using alternative stimuli (e.g., word-like symbols) in experimental comparisons to investigate the phonological and visual processes of logographical languages (e.g., Sugishita et al., 1992; Nakamura et al., 2002, 2005; and Chen et al., 2002). Such studies often failed to establish a double disassociation of neural correlates to separate the phonological and visual processes of logographical languages. Secondly, past studies failed to address differences between native and non-native speakers of such a logographical language. For instance, Chee et al. (2000), Lee et al. (2004), and Yoon et al. (2005) did not recruit native English speakers (except Chinese-English bilinguals) to participate in experimental conditions that could be used as a control/referential comparison for Chinese and English processing.

Most importantly, Mechelli et al. (2003) criticized that word-nonword comparisons in current neuroimaging studies produced inconsistent results that made it difficult to associate these data with input modalities of language processing. Word and nonword reading has been widely implemented to investigate subcomponents of the perceptual processing of alphabetic languages like English. However, discussions of whether a nonword reading condition is more related to activation of perceptual processing, or semantic inhibition (e.g., reduced activation of semantic processing underlying phonological access) are still unsettled (cf. Binder et al., 2003; 2009; Mechelli et al., 2003; Rumsey et al., 1997).

To contrast the semantic component of language processing, it is critical to make comparisons with a matched control condition that does not require semantic access. Although by definition, word-like nonwords provide similarities of perceptual representations of words without intentional connections to any associated knowledge and meaning (Simos et al., 2002), some complexities of using nonword reading have been identified. For example, findings of reading words relative to nonwords (word-nonword contrasts) were found to be more inconsistent than those comparing nonword reading with word reading (nonword-word contrasts) across studies (Mechelli et al., 2003).

Significant BOLD activations by word and nonword were also observed differently between analyses in individual level and in group level. Some increased activities caused mainly by effects of reading words relative to nonwords and fixations (a visual symbol that serves as a control condition that allows the subject’s vision to be fixated at a designate spot) were observed only at an individual level. In group analyses where intersubject variability is normalized, consistent effects of reading words might be due to deactivation for reading nonwords relative to fixations rather than increased activity for reading words relative to fixation (Mechelli et al., 2003). This issue again weakened the reason to employ nonword reading in experimental design.

Other factors such as insufficient number of subjects, variations of stimuli duration, task difficulty, handedness, gender, age, and literacy could also contribute to produce false-positive results of observed BOLD activations in word reading conditions (Démonet, 2005). These issues again suggest the necessity of refining the details of experimental design.

Conclusion

By reviewing a collection of studies that reflect syntactic, pragmatic, and semantic aspects of human icon processing, Chapter Two established the following theses in preparation for empirical investigations that ensue.

Firstly, because of the etymological connections between modern icons and logographical words, an icon is more than just a picture, and instead can be regarded as a logogram. Secondly, by replacing texts in GUIs, end-users' behavioral and cognitive processes have become a significant subject in HCI research where discourses have focused on the effect of icons that influences how people can efficiently and accurately interpret meanings of what they perceived. Lastly, new approaches such as neuroimaging methods have emerged to investigate the connection between brain functions and semantic productions of human information processing. Such neuroimaging methods have provided promising potentials to practically and empirically examine this dissertation's overarching research question about whether icons are cognitively processed as pictures or logograms by people.

In consequence, the author follows the footsteps of studies in: 1) normative ratings of icon taxonomy; 2) behavioral studies of the effect of icons and other visual stimuli, and 3) neuroimaging studies of symbol interpretations in contrast to other visual stimuli, and describes the design of a series of three studies in the next chapter using statistical, behavioral, and neuroimaging methods for this dissertation's research questions.

Chapter Three: Method

Overview

This dissertation includes three studies to investigate how people interpret four types of visual information including icons, pictures, Chinese characters, and English words. Each study collected measures that represent domains of 1) syntactic representation, 2) pragmatic interaction, and 3) semantic production of people's processes of interpreting these four types of visual information. Figure 3.1 shows the research dimensions of this dissertation.

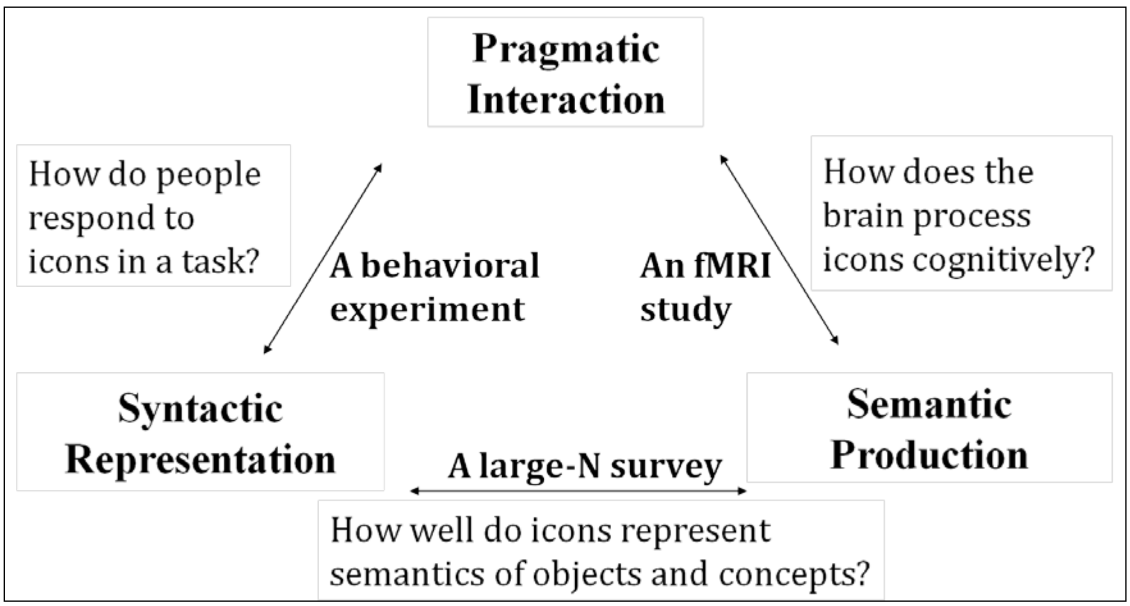

Figure 3.1 Research Dimensions

Research Questions, Designated Studies and Objectives

This dissertation aimed to answer an overarching research question, "Do people behaviorally and cognitively process icons as pictures or logographical words?" According to the research dimensions of this dissertation (Figure 3.1), this overarching question was divided into three questions that represented relations among the research dimensions: 1) how well do icons represent semantics of objects and concepts? 2) how do people respond to icons in a behavioral task? and 3) how does the brain process icons cognitively?

Three studies were designed to answer these questions. The first study was a survey of 500 stimuli including icons, pictures, single English words, and single Chinese characters. The purpose of Study One was to investigate how well icons represented semantics of objects and concepts in contrast to pictures, English words, and Chinese characters. Two objectives of the first study aimed 1) to examine how these four different types of stimuli were semantically interpreted in a quantitative scale (i.e., being a concrete stimulus by representing an object versus being an abstract stimulus by representing a concept), and 2) to select statistically concrete and abstract stimuli for the second and the third studies.

The second study was a behavioral experiment that measured how fast people could correctly interpret the meaning of icons, pictures, single English words, and single Chinese characters. By displaying the statistically concrete and abstract stimuli selected from the first study in an experimental sequence, test participants used a two-button device to perform a semantic decision task to judge whether the presented stimulus was concrete or abstract for its meaning in a limited period of time. Two objectives of the second study aimed 1) to examine how people behaviorally responded to these four types of visual information in terms of accuracy and efficiency, and 2) to select proper test participants for the third study.

The third study employed fMRI methodology to identify brain regions that were employed to read icons in contrast to neural correlates of reading pictures, English words, and Chinese characters in order to determine if the same or different neural networks were required to process these four types of stimuli. Test participants of Study Three were selected based on their demographic and behavioral data in Study Two. They performed the same behavioral task in Study Two inside the magnetic resonance (MR) scanner while their brains were scanned. Two objectives of the third study were 1) to make an empirical association between Study Two's behavioral data and neural activations that were modulated by icons, pictures, single English words, and single Chinese characters, and 2) to establish premises regarding whether icons and Chinese characters stimulated the same language representations in the brain and had distinct patterns of responses that were different from the perception of pictures.

Independent and Dependent Variables

There are four factors as independent variables: F1—types of stimuli (icons, pictures, Chinese characters, and English words), F2—types of semantics (concrete and abstract), F3—experimental runs (run 1, run 2, run 3, and run 4), and F4—native language literacy (English speakers, "EN", and Chinese speakers, "CH"). F1, F2 and F3 are within-subject variables and F4 is a between-subject variable. Study One has only F1, F2 and F4, but Study Two and Study Three have all four factors. Table 3.1 lists these factors and their conditions.

The dependent variables include different types of measures according to each study's design. Study One collects statistical rating scores of stimuli. Study Two records behavioral measures of the test participant's reaction times and numbers of errors during the process of interpreting stimuli. Accuracy is measured by numbers of errors and efficiency is determined by participants' reaction times in milliseconds. Study Three collects fMRI imaging data including structural magnetic resonance imaging scans and blood-oxygenation-level dependent (BOLD) signals of hemodynamic responses of the test participant's brain that determine modulated activations of brain regions that are associated with the experimental conditions.

<table>
<tr><td colspan="33">Within-subject variables</td></tr>
<tr><td>F 1</td><td colspan="8">Chinese Characters</td><td colspan="8">English Words</td><td colspan="8">Icons</td><td colspan="8">Pictures</td></tr>
<tr><td>F 2</td><td colspan="4">Concrete</td><td colspan="4">Abstract</td><td colspan="4">Concrete</td><td colspan="4">Abstract</td><td colspan="4">Concrete</td><td colspan="4">Abstract</td><td colspan="4">Concrete</td><td colspan="4">Abstract</td></tr>
<tr><td>F 3</td><td>1</td><td>2</td><td>3</td><td>4</td><td>1</td><td>2</td><td>3</td><td>4</td><td>1</td><td>2</td><td>3</td><td>4</td><td>1</td><td>2</td><td>3</td><td>4</td><td>1</td><td>2</td><td>3</td><td>4</td><td>1</td><td>2</td><td>3</td><td>4</td><td>1</td><td>2</td><td>3</td><td>4</td><td>1</td><td>2</td><td>3</td><td>4</td></tr>
<tr><td colspan="33">Between-subject variables (F4): English speakers and Chinese speakers</td></tr>
<tr><td colspan="33">Dependent Variables (measures):
Study 1 (no F3): statistical rating scores
Study 2: numbers of errors and reaction times (in milliseconds)
Study 3: fMRI imaging data</td></tr>
</table>

Table 3.1 Independent and Dependent Variables

Hypotheses

Study One did not have a specific alternative hypothesis, but it was assumed that the rating scores should be affected by the experimental conditions and there might be a demarcation between graphical types of visual stimuli (i.e., icons and pictures) and textual type of visual stimuli (English words and Chinese characters).

Study Two assumed that people’s reaction times and numbers of errors during the process of semantic interpretation should be affected by the experimental conditions. It is hypothesized that people would respond slower and make more mistakes with graphical types of visual stimuli than textual type of visual stimuli. Also, it is hypothesized that people would respond faster and make fewer mistakes with concrete stimuli than abstract stimuli.

Study Three took a proposition that predicted patterns of fMRI data modulated by icons would match those of Chinese characters and mismatch those of pictures within the same semantic system of the brain. Match and mismatch between patterns of modulated fMRI data were in terms of comparing distributions of significant BOLD signals in Talairach coordinates[1]. In other words, no significant contrasts in brain regions would be found between conditions of interpreting icons and Chinese characters, whereas significant contrasts should be identified between conditions of interpreting icons and pictures. Factors of represented semantics and native language literacy would also have effects on the dependent variables. Their interactions with other factors would also have influences in measures. For example, concrete stimuli were expected to be processed more efficiently than abstract stimuli and to have different fMRI contrasts (cf. Kiehl et al., 1999; Fiebach & Friederici, 2003). Chinese native speakers might engage different brain regions in the logogram condition in contrast to English native speakers' brain regions in the word condition (cf. Kim et al., 1997; Yoon et al., 2006). Therefore, English native speakers' data of reading Chinese characters could be used as a control condition.

Conclusion

Chapter Three serves to provide a brief overview of this dissertation's research questions, objectives, hypotheses, and methodology to investigate whether people cognitively process icons as logographical words by a series of three consecutive studies. Details of each study's research methods and results are described in Chapter Four for Study One, Chapter Five for Study Two, and Chapter Six for Study Three.

[1] Talairach coordinates is a coordinate system of the human brain attributed to Jean Talairach (cf. Mazoyer, 2008) that is used to describe the location of brain structures independent from individual differences in the size and overall shape of the brain. In the Talairach coordinate system, with Anterior Commissure being at coordinate 0, 0, 0, the right hemisphere has positive X values, the anterior part has positive Y values, and the superior part has positive Z.

Chapter Four: Study One—Statistical Measures of Semantic Interpretations

Experimental Design

The design of Study One was to investigate how concrete or abstract icons represent the semantics of objects and concepts in terms of normative ratings in contrast to other types of visual information including pictures, single English words, and Chinese characters.

Participants

The survey used in Study One was open to the general public. Two groups of test participants were recruited: Chinese native speakers who also read English and English native speakers who did not read Chinese logograms. Since Study One was designed to be a large-N study, the number of valid responses to the questionnaire was expected to be over 100.

Test Materials

Four types of stimuli were used in the survey: 135 icons, 113 pictures, 127 single Chinese characters, and 125 single English words for a total of 500. This section describes the criteria used in selecting these stimuli. A complete list of the 500 stimuli used in the questionnaire is in Appendix A.

- Icons: By the icon design's names or labels assigned to each symbol and the definition of concrete and abstract noun classification, these 135 stimuli included 69 concrete ISOTYPE (International System of TYpographic Picture Education) symbols that represented a single object or substance that existed physically (Figure 4.1), and 66 abstract ISOTYPE symbols that represented a state, events, concept, or feeling (Figure 4.2) that also included conceptual and cultural symbols (Figure 4.3). All icons were adapted and modified from symbols designed by

Gerd Arntz (1900-1988), the Manual on Uniform Traffic Control Devices (MUTCD) 2003 Edition with Revision No.1, and the AIGA (the Professional Association for Design). All icons were modified with the same design style of the AIGA symbols and formatted into bitmap images that had the same image size (470 x 470 pixels) and color (black-and-white images with grey scale contrasts).

Figure 4.1 Examples of Concrete Icons: Cup, Woman, Helicopter and Extinguisher

Figure 4.2 Examples of Abstract Icons: Drinking, Waiting, Inquiring and Inspecting

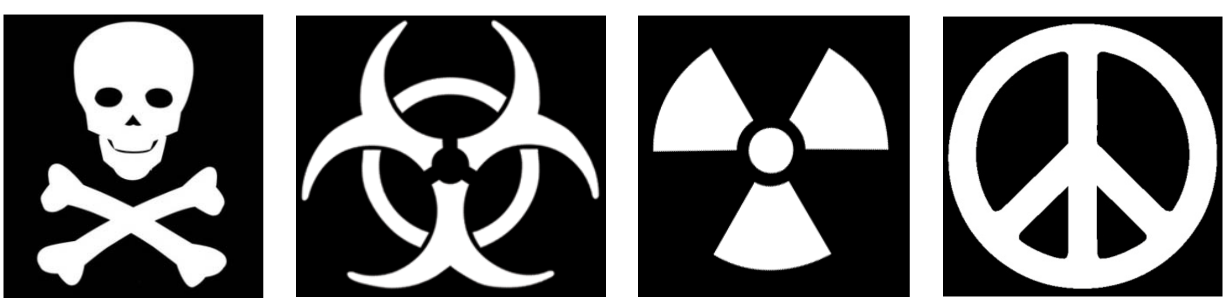

Figure 4.3 Examples of Conceptual Icons: Death, Biohazard, Radiation and Peace

- Photographic pictures: By the author's choice of nouns assigned to each picture and the definition of concrete and abstract noun classification, these 113 stimuli included 52 concrete photographs that faithfully presented a single object or substance that existed physically (Figure 4.4), and 61 abstract photographs that artistically presented a state, event, concept, or feeling that were open to various interpretations (Figure 4.5). These stimuli included pictures of objects in the ETH-80 database developed by Leibe &Schiele (2003) and pictures selected from Google Images (http://images.google.com/) by using high-frequency nouns of objects and concepts as key words of search. All pictures were modified and formatted into bitmap images that had the same image size (470 x 470 pixels) and color (black-and-white images with grey scale contrasts).

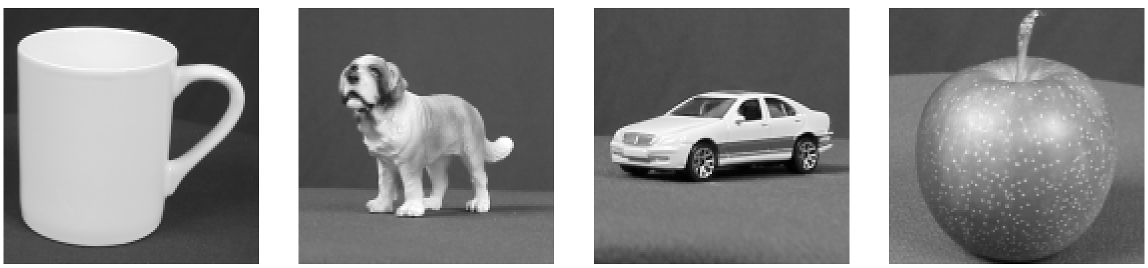

Figure 4.4 Examples of Concrete Pictures

Figure 4.5 Examples of Abstract Pictures

- High-frequency logograms (single Chinese characters): High-frequency Chinese characters were used to control the effect of unfamiliarity that would affect reaction times within word conditions. In addition, different word frequencies would also result in differences in modulated BOLD contrasts that were associated with different input modalities (e.g., phonological and orthographical/logographical processing) of single word reading (cf. Démonet et al., 2005). Controlling word frequency would increase the internal validity and reliability of contrasting the logogram and word conditions with other experimental conditions (i.e., icons and pictures). By the definition of concrete and abstract noun classification in Chinese, these 127 stimuli included 64 concrete nouns that refer to objects and substances that existed physically, including people and animals, and 63 abstract nouns that referred to states, events, concepts, feelings, or qualities that had no physical existence (e.g., freedom, happiness, time, and speed). All nouns were sampled from a word list of the 1000 most frequently used Chinese characters from Knowledge Essential for Writing Characters and the Chinese Writing System by Der-lin Chao, Ph.D. [2] All logograms were formatted into bitmap images that had the same image size (470 x 470 pixels) and color (black-and-white images with grey scale contrasts).

- High-frequency words (single English words): High-frequency English words were used for the same reason as the Chinese characters. By the definition of concrete and abstract noun classification in English, these 125 stimuli included 61 concrete and 64 abstract nouns that had the same definition as high frequency logograms. All nouns were sampled from a word list of 1200 high-frequency writing words from Sitton Spelling Sourcebook Series by Egger Publishing, Inc.[3] All words were formatted into bitmap images that have the same image size (470 x 470 pixels) and color (black-and-white images with grey scale contrasts).

[2] http://www.chineseliteracy.net/content/charcrossref.htm
[3] http://school.elps.k12.mi.us/donley/classrooms/berry/sitton_spelling_activities/4thgrade_spelling/sitton_word_list.htm

Survey Design, Hosting Website and Method of Distributing

The web-based questionnaire had two parts. The first part collected anonymous demographic information including the native language, gender, age range, education level, and e-mail address (optional). The second part consisted of 500 questions that listed the 500 stimuli in a random order for the survey participant to sort each stimulus into one of these five categories: very concrete, concrete, abstract, very abstract, and N/A (cannot decide). Invisible to the participant, each category was given a numerical code to represent the rating score of the evaluated stimulus (i.e., very concrete = 1; concrete = 2; abstract = 3; very abstract = 4; N/A = 0). The participant was given a general definition of what concrete and abstract stimuli were. The general definition suggested that if the stimulus represented a physically existing object such as a cup, it would be concrete; if the stimulus represented a concept such as "love," it would be abstract. The participant was asked to choose the best category that fit the presented stimulus based on his or her interpretations of its meaning. The reason for asking the participants to interpret presented stimuli by the concrete and abstract categories corresponds to the classifications of icon taxonomy (cf. Wang et al. 2007), types of pictorial learning (cf. Kunnath et al. 2005), and the classification of concrete and abstract nouns in English and Chinese. A print version of the web-based questionnaire including all 500 stimuli is attached as Appendix A.

A commercial website (www.surveymonkey.com) was chosen to host the questionnaire from January 29th to July 4th, 2010. The Uniform Resource Locator (URL) of the questionnaire was distributed via six private e-mail lists (owned by institutions at the University of Texas at Austin), two academic research websites [4, 5] and one social network [6] to reach potential participants in the general public.

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[4] Online Social Psychology Studies (http://www.socialpsychology.org/expts.htm)

[5] Psychology Research on the Net (http://psych.hanover.edu/research/exponnet.html)

Analysis and Results

Data Validation

Data from Study One were collected from January 29th to July 4th, 2010. A total number of 316 participants including 78 students who were recruited via the subject pool program in the Department of Psychology at the University of Texas at Austin participated in the survey. Only 215 participants finished all 500 questions, and 211 subjects' data were valid without systematically biased entries (e.g., choosing the same category for all 500 stimuli). As a result, the questionnaire response rate is 66.8 percent (211 valid responses out of 316 participants).

Data Analysis

One objective of the first study is to examine how these 500 stimuli are semantically interpreted in a quantitative scale in terms of being a concrete stimulus representing an object versus being an abstract stimulus by representing a concept. Descriptive statistics and analysis of variance (ANOVA) were performed on the mean rating score of each stimulus to determine if there were significant disparities among these four types of stimuli of visual information. ANOVA with $p<.01$ was conducted on the rating scores to determine the significant demarcation between scores of concreteness and abstractness that are associated with the stimuli.

Another objective of this study is to select statistically concrete and abstract stimuli for the second and third study. If a stimulus' z-score is higher than zero, it will be marked as a concrete stimulus. If a stimulus' z-score is lower than zero, it will be marked as an abstract stimulus. A final set of the 25 most concrete and 25 most abstract of each experimental condition including 50 icons, 50 pictures, 50 logograms, and 50 words was selected. These stimuli were

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[6] Facebook (http://www.facebook.com)

used again as testing materials in Study Two and Study Three (see Chapter Five and Chapter Six). The final set of these 200 stimuli is presented in the Appendix B.

Demographics of Participants

Two groups of participants were recruited: one consisted of 76 Chinese speakers who also read English and the other of 135 English speakers who do not read Chinese. All participants completed four demographic questions regarding the participant's native language, gender, age, and education level. Table 4.1 shows these 211 participants' demographics.

Language	English Chinese	64% (135) [a] 36% (76) [b]
Gender	Male Female	36% (76) 64% (135)
Age	18-25 26-35 35-45 46+	64.5% (136) 23.2% (49) 7.1% (15) 5.2% (11)
Education	High School College Graduate School	14.2% (30) 61.1% (129) 24.6% (52)

a. Includes 127 native English speakers and 8 English-as-second-language (ESL) speakers who do not read Chinese.
b. Includes 56 native Chinese speakers (ESL) and 12 Chinese-English bilinguals, and 8 Chinese-as-second-language (CSL) speakers.

Table 4.1 Demographics of Participants in Study 1 (N=211)

Descriptives of Overall Means

The questionnaire was made of 500 stimuli including 135 icons (69 concrete and 66 abstract), 125 English words (61 concrete and 64 abstract), 113 pictures (52 concrete and 61 abstract), and 127 Chinese characters (64 concrete and 63 abstract). Subjects (N=211) were asked to rate each stimulus by four scales: very concrete (1), concrete (2), abstract (3), and very abstract (4). There was also an option of "N/A (0)" if the subject could not determine the rating. Each stimulus' rating scores are means of 211 subjects' rating scores except Chinese characters' rating scores that are means of those 76 Chinese readers. All means are calculated by excluding scores of "N/A (0)." Table 4.2 summarizes the descriptive statistics of these 500 stimuli's rating scores.

Mean	Median	Mode	Variance	Std. Deviation	Min.	Max.	Range
2.20	2.20	2.46	.171	.414	1.48	3.26	1.78

Table 4.2 Descriptives of Overall Rating Scores (N=500)

There are no significant outliers and the sample is normally distributed by the non-parametric model within normal parameters of one-sample Kolmogorov-Smirnov test (Mean = 2.23, Std. Deviation = .41). Figure 4.6 shows the histogram and normal quantile-quantile plot of rating scores.

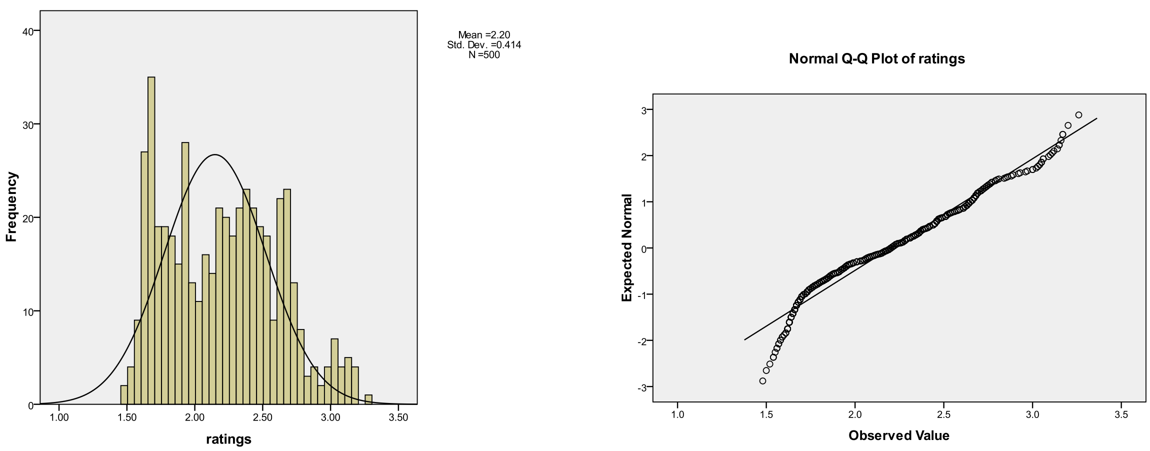


Figure 4.6 Histogram and Normal Quantile-quantile Plot of Overall Rating Scores

Descriptives of Group Means

Subjects who read Chinese (n=76) rated all 500 stimuli while subjects who only read English (n=135) skipped those 127 Chinese characters and rated only 373 stimuli. Table 4.3 summarizes the group statistics of rating scores. There is no significant mean difference between rating scores given by the Chinese and English groups (t (871) =.301, not significant at p=.01). Therefore, the variance of the rating scores was not affected by the language factor.

Language Group	N	Mean	Std. Deviation
Chinese (n=76)	500	2.23	.421
English (n=135)	373	2.22	.429

Table 4.3 Group Statistics of Rating Scores

Descriptives and ANOVA of Stimuli Means by Types of Stimuli

Figure 4.7 shows histograms of ratings scores that are grouped in different types of stimuli.

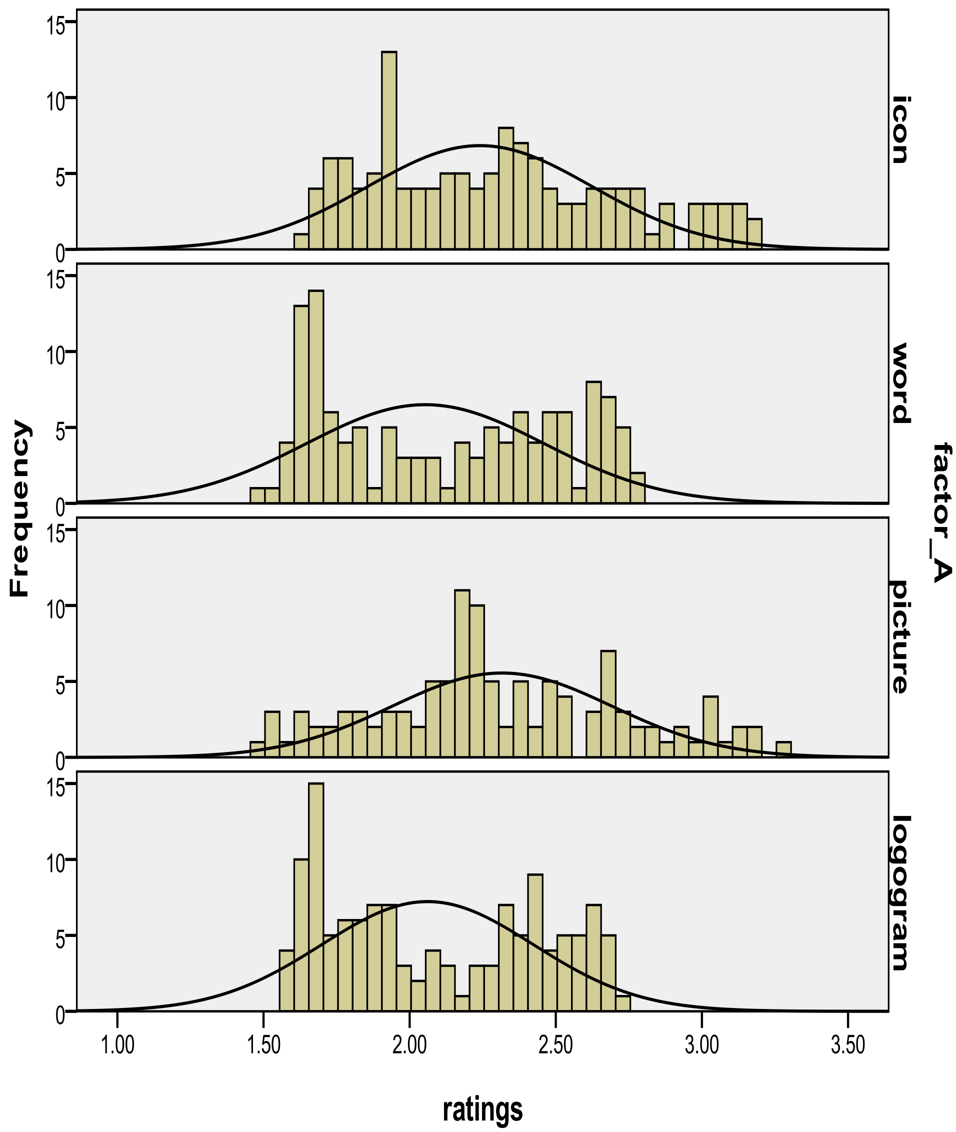


Figure 4.7 Histograms of Rating Scores by Types of Stimuli

The variance of mean rating scores within each type of these stimuli is equal (Levene statistic (3, 496) = .564, not significant at $p=.01$). Table 4.4 and Figure 4.8 indicate that pictures' mean rating score is the highest, followed by icons, English words, and Chinese characters. ANOVA shows that there is a significant mean difference among these four types of stimuli ($F(3, 496) = 10.906$, $p<.01$). Post-hoc tests (Tukey HSD) show that the mean rating score of icons is significantly higher than English words (.19 at the .01 level) and Chinese characters (.21 at the .01 level). The mean rating score of pictures is also significantly higher than English words (.20 at the .01 level) and Chinese characters (.22 at the .01 level).

Stimuli	n	Mean	Std. Deviation	Min.	Max.
Icons	135	2.30	.42	1.63	3.20
English Words	125	2.11	.40	1.48	2.80
Pictures	113	2.31	.43	1.50	3.26
Chinese Characters	127	2.09	.36	1.57	2.71

Table 4.4 Descriptives of Stimuli Means by Types of Stimuli

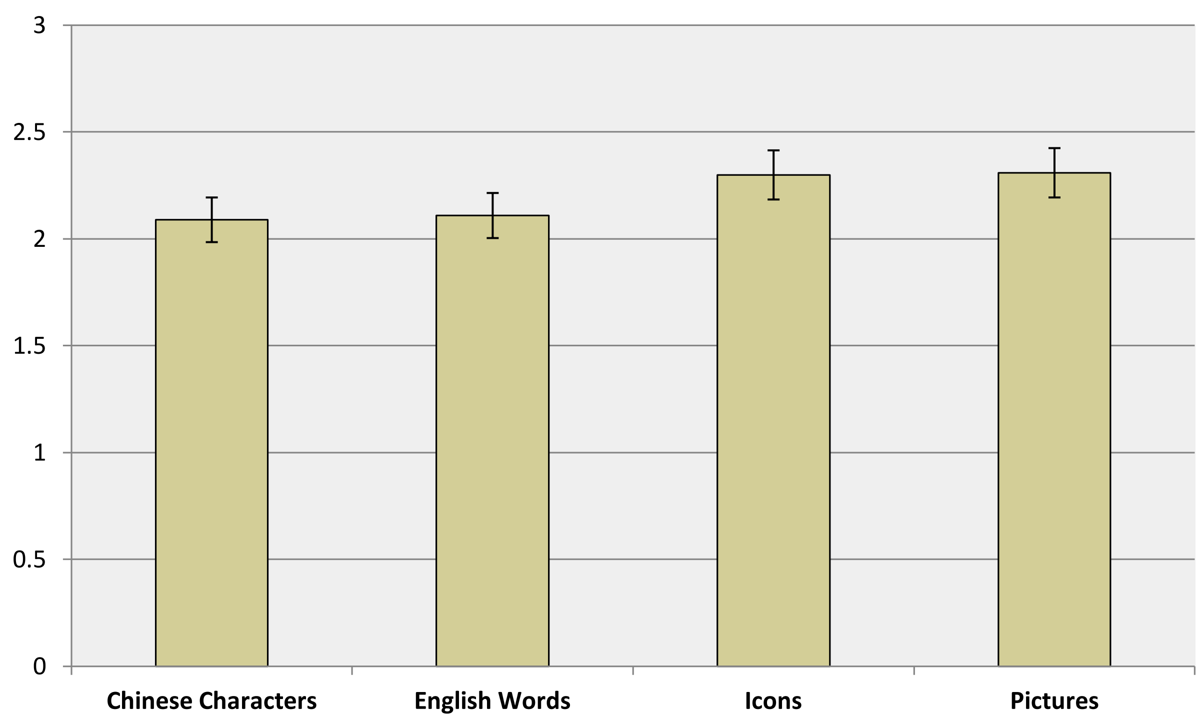


Figure 4.8 Stimuli Means by Types of Stimuli

The mean difference between icons and pictures is not significant, nor is it between English words and Chinese characters. Table 4.5 shows the homogeneous subsets of these groups of stimuli.

		Subset for alpha = 0.01	
Stimuli	n	1	2
Chinese characters	127	2.09	
English words	125	2.11	
Icons	135		2.30
Pictures	113		2.31
Sig.		.965	.994

Means for groups in homogeneous subsets are displayed by Tukey HSD[a,b].

a. Uses Harmonic Mean Sample Size = 124.490.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.5 Homogeneous Subsets of Stimuli Means by Types of Stimuli

Descriptives and ANOVA of Stimuli Means by Types and Semantics

Figure 4.9 shows histograms of ratings scores that are grouped in different types of stimuli and supposed semantics. From top to bottom: concrete icons, abstract icons, concrete English words, abstract English words, concrete pictures, abstract pictures, concrete Chinese characters, and abstract Chinese characters.

The variance of mean rating scores within each type of these stimuli is NOT equal (Levene statistic (7, 492) = 13.90, $p< .01$). This can be observed in the histograms (Figure 4.10) where the distribution of rating scores of icons and pictures is more spread out than English words and Chinese characters in both concrete and abstract categories. Table 4.6 and Figure 4.8 indicate that abstract icons' mean rating score is the highest, followed by abstract pictures, abstract English words, abstract Chinese characters, concrete icons, concrete pictures, concrete

Chinese characters, and concrete English words. ANOVA shows that there is a significant mean difference among these eight types of stimuli ($F(7, 492) = 112.687$, $p<.01$).

Post-hoc tests (Tukey HSD) reveal that the mean rating score of abstract icons is significantly higher than abstract English words (.14 at the .01 level), abstract Chinese characters (.19 at the .01 level), concrete icons (.57 at the .01 level), concrete pictures (.58 at the .01 level), concrete Chinese characters (.81 at the .01 level), and concrete English words (.83 at the .01 level). The mean rating score of abstract pictures is also significantly higher than abstract Chinese characters (.16 at the .01 level), concrete icons (.55 at the .01 level), concrete pictures (.56 at the .01 level), concrete Chinese characters (.79 at the .01 level), and concrete English words (.81 at the .01 level).The mean rating score of abstract English words is significantly higher than concrete icons (.43 at the .01 level), concrete pictures (.44 at the .01 level), concrete Chinese characters (.68 at the .01 level), and concrete English words (.70 at the .01 level). The mean rating score of abstract Chinese characters is also significantly higher than concrete icons (.38 at the .01 level), concrete pictures (.39 at the .01 level), concrete Chinese characters (.63 at the .01 level), and concrete English words (.65 at the .01 level). The mean rating score of concrete icons is significantly higher than concrete Chinese characters (.24 at the .01 level) and concrete English words (.26 at the .01 level). The mean rating score of concrete pictures is also significantly higher than concrete Chinese characters (.23 at the .01 level) and concrete English words (.25 at the .01 level). The mean differences between 1) abstract icons and abstract pictures, 2) abstract pictures and abstract English words, 3) abstract English words and abstract Chinese characters, 4) concrete icons and concrete pictures, and 5) concrete Chinese characters and concrete English words are not significant. Table 4.7 shows the homogeneous subsets of these groups of stimuli.

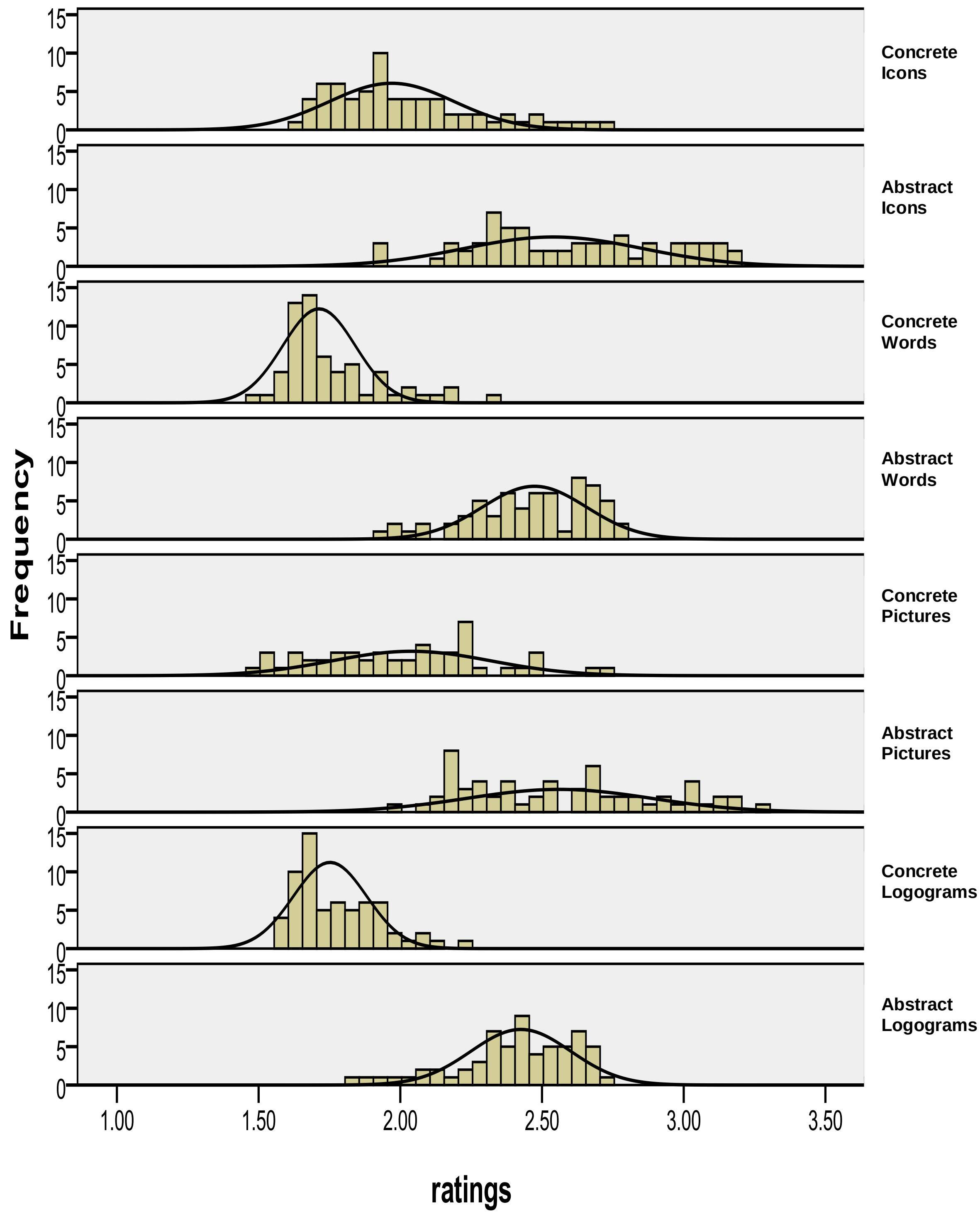


Figure 4.9 Histograms of Rating Scores of Stimuli by Types and Semantics

Stimuli	n	Mean	Std. Deviation	Min.	Max.
Concrete Icons	69	2.02	.27	1.63	2.75
Abstract Icons	66	2.59	.34	1.91	3.20
Concrete English Words	61	1.75	.17	1.48	2.31
Abstract English Words	64	2.45	.22	1.95	2.80
Concrete Pictures	52	2.01	.30	1.50	2.74
Abstract Pictures	61	2.57	.34	1.99	3.26
Concrete Chinese Characters	64	1.78	.15	1.57	2.22
Abstract Chinese Characters	63	2.40	.21	1.85	2.71

Table 4.6 Descriptives of Stimuli Means by Types and Semantics

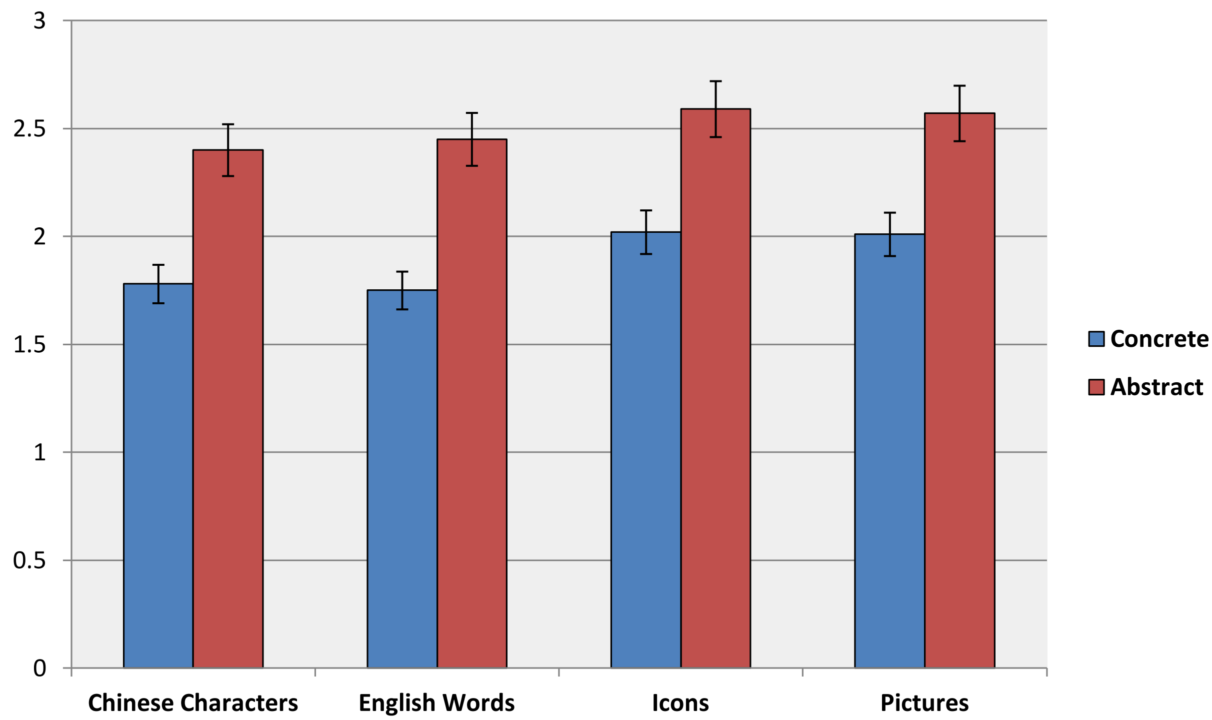


Figure 4.10 Stimuli Means by Types and Semantics

Stimuli	n	Subset for alpha = 0.01			
		1	2	3	4
Concrete English Words	61	1.75			
Concrete Chinese Characters	64	1.78			
Concrete Pictures	52		2.01		
Concrete Icons	69		2.02		
Abstract Chinese Characters	63			2.40	
Abstract English Words	64			2.45	2.45
Abstract Pictures	61				2.57
Abstract Icons	66				2.59
Sig.		1.000	1.000	.971	.060

Means for groups in homogeneous subsets are displayed by Tukey HSD[a,b].

a. Uses Harmonic Mean Sample Size = 62.119.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.7 Homogeneous Subsets of Stimuli Means by Types and Semantics

Findings and Discussion

Key Findings and Implications

The first study has three key findings: 1) the language differences of subjects have no significant influences on how normative ratings of these 500 stimuli are given; 2) information in forms of graphical representations (i.e., pictures and icons) are statistically more abstract (ambiguous) than textual representations (i.e., single English words and Chinese characters), and 3) such a demarcation between graphical representations and textual representations of information remains in both concrete and abstract stimuli.

There is no significant mean difference between rating scores of stimuli given by the Chinese-reading participants and English-reading participants in this study. The variance of the rating scores of these 500 stimuli was not affected by the language factor. This result indicates that when seeing the same stimulus they can interpret the meaning of, how the Chinese speaker rates that stimulus is not different from how the English speaker does. Although the objectives of Study One were not initially designed to test whether the Chinese-reading participants would sort the same stimuli into the same categories as the English-reading participants, it is implied that the language or cultural differences of subjects had little effect on how they interpret these 500 stimuli.

In the first level analysis of the main factor, the normative rating scores of pictures and icons were found to be significantly higher than English words and Chinese characters, while there were no differences between pictures and icons, nor were there between these two languages' rating scores (Table 4.6). It is implied that on average, pictures and icons are statistically more abstract than texts. The statistical demarcation between pictures and texts is not surprising since pictures are presumed open to a variety of interpretations instead of a single meaning like a word. However, it is unexpected to find no statistical differences between the mean rating scores of pictures and icons since many have claimed that carefully crafted icons should provide better access to their designated meanings (cf. Abdullah & Hübner, 2006; Caplin, 2001; and Horton, 1994). Such a claim is further challenged by the significant difference found between the mean rating scores of icons and texts. Having significantly higher rating scores than both English words and Chinese characters, icons are found to be less concrete than their text counterparts on average.

Moreover, in the second level analysis where stimuli were further classified into concrete and abstract groups, such relationship among icons, pictures and texts still remained the same (Table 4.7). In general, it is again not surprising that abstract stimuli have significantly higher rating scores than concrete stimuli on average, but icons do not separate from pictures and still have significant distances from texts in terms of their mean rating scores. As Table 4.7 shows, even concrete icons are statistically more abstract than concrete nouns in both languages on average.

It is important to clarify that findings presented in Table 4.6 and 4.7 cannot apply to predict or assert that a certain icon will be more or less concrete/abstract than pictures/texts in any individual case. Taking Table 4.8 as examples, normative ratings of an icon in contrast to other stimuli that represent the same meaning are not absolute and objective in every case. Therefore, this study opposes the idea suggested in previous studies (e.g., McDougall et al., 1999, 2000 and Isherwood et al., 2007) to use normative ratings (i.e., concreteness, complexity, familiarity, or semantic distance) as objective attributes of individual stimulus.

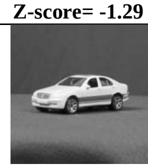
 **Z-score = -1.46**	 **Z-score= -1.29**	horse **Z-score = -1.18**	馬 **Z-score = -0.90**
 **Z-socre = -1.15**	 **Z-score = -1.73**	car **Z-score = -1.40**	車 **Z-score = -0.73**

Table 4.8 Standard Scores of Concrete Stimuli that Represent “Horse” and “Car”

Limitations and Controls

The number of Chinese-reading participants and English-reading participants was not balanced. Such a sampling limitation might reduce the internal validity of those 127 Chinese character’s normative rating scores in comparison with other stimuli in the statistical analysis.

The sample size might be too small to represent the whole population of literal Chinese and English speakers. Therefore, it is not suggested to generalize findings about language and culture factors in this study. These factors should be further analyzed with a larger number of representative participants from both English-speaking and Chinese-speaking communities in the future.

The reason why mean rating scores of pictures and icons were significantly higher than texts might be due to the fact that all text stimuli were high frequency nouns while such a factor could not be controlled while selecting those 135 icons and 115 pictures as testing materials. Although the author used high frequency nouns as references for icon names and keywords in the image search engine of Google, the same noun could be represented by different styles of icon design and a variety of pictures suggested by the search engine's internal mechanisms of relevance ranking. Controls such as selecting icons from the same designer and credible standards, and pictures from a research database were applied in attempt to reduce this factor.

Conclusion

According to the statistical analyses of normative ratings of icons, pictures, English words, and Chinese characters in terms of participants' concrete versus abstract interpretations in this study, the proposition suggesting that icons are more than just pictures or that they can be regarded as logographical words is incorrect. This proposition is further examined in Study Two and Study Three in terms of participants' behavioral responses and cognitive processes for the same concrete versus abstract interpretations for these four types of visual representation of information.

In addition, under the experimental conditions of this study, unaffected by the language factor of participants, pictures and icons are more ambiguous (i.e., having statistically significantly higher rating scores in both concrete and abstract categories) than English words and Chinese characters in term of conveying the immediate semantics of objects and concepts. In other words, like pictures, icons are more ambiguous than texts, and even concrete icons are more ambiguous than concrete texts. Findings of Study One imply that despite being carefully crafted, icons might still be fundamentally inferior to texts in communicating context to end-users. Results of this study suggest that icons are less likely to provide access to universal and unambiguous interpretations without the support of context such as localized texts.

Chapter Five: Study Two—Behavioral Measures of Semantic Interpretations

Experimental Design

The experimental design of this study was to investigate how accurately and efficiently people can interpret meaningful symbols such as icons in contrast to other types of visual information including pictures, single English words, and single Chinese characters. Two groups of test participants were recruited: one consisted of Chinese native speakers who also read English and the other had English native speakers who did not read Chinese. This study consisted of a short questionnaire used to collect participants' demographics (i.e. native language, gender, age range, handedness, and education level) and a behavioral experiment to evaluate how fast people could correctly interpret icons, pictures, English words and Chinese characters.

Test Materials

A set of 200 stimuli were selected for this study. These 200 stimuli included 50 icons, 50 pictures, 50 single English nouns, and 50 single Chinese characters (also nouns). Each type of visual information had 25 highly-comprehensible stimuli that represented concrete objects and 25 highly-comprehensible stimuli that represented abstract concepts. The criterion for selecting these 200 stimuli was based on the rating scores collected from the web-based questionnaire of Study One (see Chapter Four). These 200 stimuli needed to be maximally representative of the "concrete" and "abstract" categories so that they could be highly-comprehensible for test participants to sort into these two categories in a behavioral task without the risk of ambiguity. Thus, those stimuli with means most below or above the sample mean were marked as highly-comprehensible stimuli. In this case, the 25 lowest rated icons were selected as highly-comprehensible concrete icons ($z < -1$); the 25 highest rated icons were chosen as highly-comprehensible abstract icons ($z > 1.04$), and the same approach was applied to the rest of the stimuli types. In other words, these were 200 highly-comprehensable stimuli in two distinctive categories according to the survey ratings from Study One and test participants were expected to be able to easily judge whether a stimulus from these 200 stimuli was concrete or abstract as long as they were from the same population as the statistical norms established in Study One.

The final set of these 200 stimuli is listed in the Appendix B with their mean scores, z scores, and classification.

Stimuli Presentation Design

The stimuli presentation and subjects' behavioral task of Study Two's experiment were designed as a paradigm that was compatible for fMRI research. Such a compatible experiment was designed to complement Study Three that would collect fMRI data.

The stimuli presentation was played by the DMDX software[7] on a Dell Latitude laptop with a monitor having a 640 x 480 resolution. The presentation contained four runs. Each run had 110 trials including 25 icons, 25 pictures, 25 single Chinese characters, 25 words, and 10 null conditions. Each run contained both concrete and abstract stimuli. The null condition was a small black cross that served as a visual fixation point at the center of the screen. All stimuli were presented with a white background. The first and the third run had the same set of 100 stimuli in a different order, and the second and the forth run had the same set of another 100 stimuli also in a different order. Therefore, the participant would see the same stimulus only twice for the whole experiment.

[7] DMDX is a Win 32-based display system used in psychological laboratories around the world to measure reaction times to visual and auditory stimuli. It was programmed by Jonathan Forster at the University of Arizona (http://www.u.arizona.edu/~kforster/dmdx/dmdx.htm).

Every run started with a null condition for eight seconds and then played the first stimulus. The interstimulus interval (ISI) was two seconds. Each stimulus was presented for two seconds before the next stimulus showed up on the screen. The presentation showed stimuli continuously until it played all 110 trials for each run. Therefore, each run had exactly 228 seconds. All four runs had different sequences of playing the stimuli. Such sequences were designed according to the principles of event-related design[8]. The reason for using event-related design was to prepare for the follow-up fMRI research in Study Three, and to be consistent with the behavioral measures that would be collected in a MR scanner. The optimal sequence for each run to play the stimuli was calculated by optseq2[9] that incorporated onset times of experimental conditions to best fit the function of hemodynamic response model of the brain. The reason for choosing event-related design was to identify latency differences between neocortex regions associated with the semantic system in the brain that relied on the estimation power of the experimental conditions instead of the power of detecting a certain area[10]. In addition, using event-related design could reduce practice and fatigue effects that were often seen in experiments of blocked design (cf. Huettel et al., 2003, p. 303-313).

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[8] Event-related design is a major class of fMRI experiment (the other major class is blocked design). "The central assumption of an event-related design is that the neural activity of interest will occur for short and discrete intervals, … Stimulus that generate such short bursts of neural activity are known as events or trials. In most event-related designs, different conditions of the IV are associated with different events, … Each event is separated in time from the previous event, with an interstimulus interval, or ISI, that can range from about 2 s to 20 s depending on the goals of the experiment. This differs from typical blocked designs, which may present many stimuli consecutively within a task block. Also unlike blocked designs, the different conditions are usually presented in a random order rather than an alternating pattern. Event-related designs … emphasize that (different conditions of) stimuli are presented one at a time rather than within a block of trials (that has the same condition of stimuli)" (Huettel et al., 2003, p. 303).

[9] Optseq2 is a software tool developed at Harvard for automatically scheduling the order and timing of events for rapid-presentation event-related fMRI experiments (http://surfer.nmr.mgh.harvard.edu/optseq/).

[10] "…blocked designs are very poor at estimating the shape of the hemodynamic response, event-related designs have good estimation power. Estimation power is very important…by characterizing the precise timing and waveform of the hemodynamic response, researchers can make inferences about the relative timing of neural activity, about feedback processes, and about sustained activity within a region. Conversely, blocked designs are very good at detecting voxels with significant activity, because events are concentrated within the task blocks, whereas event-related designs have less detection power. By using semirandom event-related designs, researchers can improve detection power somewhat, so that it approaches that of blocked designs" (cf. Huettel et al., 2003, p. 311-312; Liu & Frank, 2004; Liu, 2004).

Table 5.1 summarizes the content of the presentation.

	8 seconds	220 seconds					
			Chinese characters	English words	Icons	Pictures	null
Run 1	Fixation (+)	Stimuli Set 1 Sequence 1	16 concrete	13 concrete	11 concrete	16 concrete	10
			9 abstract	12 abstract	14 abstract	9 abstract	
Run 2	Fixation (+)	Stimuli Set 2 Sequence 2	9 concrete	12 concrete	15 concrete	9 concrete	10
			16 abstract	13 abstract	10 abstract	16 abstract	
Run 3	Fixation (+)	Stimuli Set 1 Sequence 3	16 concrete	13 concrete	11 concrete	16 concrete	10
			9 abstract	12 abstract	14 abstract	9 abstract	
Run 4	Fixation (+)	Stimuli Set 2 Sequence 4	9 concrete	12 concrete	15 concrete	9 concrete	10
			16 abstract	13 abstract	10 abstract	16 abstract	

Table 5.1 Content of Stimuli Presentation

Subjects' Behavioral Task and Measure Definitions

Test participants were asked to perform a semantic decision-making task that is to sort a presented stimulus into a concrete or abstract category by determining whether it represented a concrete object or an abstract concept. The reason for asking the participants to interpret presented stimuli by the concrete and abstract categories was to correspond to previous studies about classifications of icon taxonomy (Wang et al., 2007), types of pictorial learning (Kunnath et al., 2005), and the classification of concrete and abstract nouns in English and Chinese. This task was chosen to ensure that test participants would try to process the meanings of the presented stimuli similar to the process of judging concrete and abstract nouns in language tests by understanding the meanings or words.

The participant was given a general guideline of how to sort the stimuli. The general guideline suggested that if the stimulus represented a physically existing object such as a cup, it should be sorted into the concrete category; if the stimulus represented a concept such as "love," it should be sorted into the abstract category. The participant was asked to choose the best category that fit the presented stimulus based on his or her interpretations of its meaning.

Test participants were asked to behaviorally respond to stimuli by pressing one of two different buttons on a keyboard with the index and middle fingers of their right hand. The participant was to use the right index finger to press button "1" when a concrete stimulus that represented an object appeared on the screen, and use the right middle finger to press button "2" when an abstract stimulus that represented a concept appeared on the screen. (The finger-response mapping was not counterbalanced in the experimental design for one reason—any switch of fingers in mid-study would have caused inconsistency in such a behavioral mapping and would have increased the error rates. See page 97 for further discussion about this design decision.) In addition, the participant was instructed to do nothing when he or she saw the null condition. All participants performed this task to every presented stimulus except English speakers were instructed to treat all Chinese characters as abstract since they did not and were not expected to understand the meaning of these stimuli.

In short, these behavioral responses were number coded and assigned to each buttons as the following description:

- Right index finger on button 1 (1): concrete stimuli that represent objects.
- Right middle finger on button 2 (2): abstract stimuli that represent concepts. English speakers were instructed to respond to all Chinese characters with this response.
- No response (0): null conditions.

Participants were instructed to perform the task based on their semantic interpretations of the presented stimuli without being informed that there were statistical consensuses on each stimulus' semantics according to the data of Study One. The presentation did not provide feedback to the test participants to inform them whether their response to each stimulus was “correct” or not (i.e., sorting a presented stimulus into a category that was consistent with the statistical norms in the previous study) and would keep playing consecutive stimuli. Participants were instructed not to linger on a previous trial once they had made a response and to focus on the next one even if they thought that they had made a mistake sorting the presented stimulus into a wrong category. In addition, the test participant had to administer a response to each stimulus within the first 1.8-second period of the two-second ISI. If the subject had failed to respond in this allotted 1.8 second during each trial, the trial was counted as a slip. This 1.8-second constraint on participants’ reaction time was to avoid mismatching the current reaction time to the next stimulus presentation. This control allowed DMDX to have a 0.2 second interval to switch the display from the current stimulus to the next one so that the onset time of each stimulus could be precisely maintained between the two-second ISIs. All test participants repeated the same task for all four runs and could take a short break between runs per requests.

Participants’ reaction times (in milliseconds) and numbers of errors were recorded by DMDX as behavioral measures. Reaction time was defined as the period of time that started at the moment when the stimulus was shown on the screen and ended at the moment when the participant issued a response. Every valid measure of participant’s reaction time for each trial had to be shorter than 1.8 seconds. Errors were counted when the participant either exceeded the 1.8-second constraint to respond to the trial or responded incorrectly (including mistakes that were different from the statistical norms established in Study One, and slips that were not what were intended by the test participant). Reaction times of such errors would be excluded from data analyses.

Analysis and Results

Data Validation

All sessions of the experiment with these 78 participants were conducted in a non-disturbed indoor lab from September 27th to November 2nd, 2010. Each participant spent approximately 45 to 60 minutes to complete the demographic survey and the behavioral experiment including giving their informed consent for participating in the study. All 78 participants' behavioral data including reaction times and error counts were successfully recorded and checked.

Data Analysis

ANOVA for repeated measures was employed to analyze collected data. F value with Greenhouse-Geisser corrected df was used to determine significant mean differences between factors unless such contrasts had passed Mauchly's test of sphericity (cf. Geisser & Greenhouse, 1958; Mauchly, 1940). The statistical analysis tested the effects of IVs, and interactions among IVs in order to determine if they had influences resulting in significant differences of estimated means of each condition's reaction times and error counts of participants' behavioral performance.

Demographics of Participants

Undergraduate and graduate students of the University of Texas at Austin were participants in this study. Two groups of test participants were recruited: one consisted of 33 Chinese speakers who also read English and the other had 45 English speakers who do not read Chinese. Table 5.2 shows these 78 participants' demographics.

Language	English Chinese	57.7% (45) [a] 42.3% (33) [b]
Gender	Male Female	50.0% (39) 50.0% (39)
Age	18-25 26-35 35+	23.1% (18) 64.1% (50) 12.8% (10)
Education	College Graduate School	10.3% (8) 89.7% (70)
Handedness	Right-Handed Left-Handed	91.0% (71) 9.0% (7)

a. Includes 43 native English speakers and 2 English-as-second-language (ESL) speakers who do not read Chinese.

b. Includes 31 native Chinese speakers (ESL) and 2 Chinese-English bilinguals.

Table 5.2 Demographics of Participants in the Second Study (N=78)

Findings about Accuracy in Performance

There were significant contrasts among numbers of errors in all within-subject factors including different experimental runs (Greenhouse-Geisser F (2.345, 178.218) = 309.947, p< .01), represented semantics (concrete vs. abstract) (F (1, 76) = 26.653, p< .01) and types of stimuli (Greenhouse-Geisser F (2.106, 160.066) = 201.098, p< .01).

Pair-wise comparisons of different experimental runs indicated that participants made significantly more errors in the first run (mean = 2.963, significant mean differences in contrast to all other runs at p = .01), and significantly fewer errors in the fourth run (mean = .964, significant mean differences in contrast to all other runs at p = .01). The difference between the second and the third run's mean error was not significant at p = .05, but their mean errors were both significantly lower than the first run and significantly higher than the fourth run (p< .01). Pair-wise comparisons of different represented semantics indicated that participants made significantly more errors with abstract stimuli (significant mean difference = .713 at p = .01). Pair-wise comparisons of different types of stimuli indicated that people made significantly more errors with icons (mean = 2.752, significant mean differences in contrast to Chinese characters

[2.411 more] and English words [2.061 more] at p = .01) and pictures (mean = 2.681, significant mean differences in contrast to Chinese characters [2.341 more] and English words [1.991 more] at p = .01). The mean difference between errors made with icons and pictures was not significant at p = .05, but subjects made significantly more errors (.35) with English words than Chinese characters at p= .01.

There were significant interactions in runs*semantics (Greenhouse-Geisser F (2.413, 183.363) = 37.648, p< .01), runs*stimuli (Greenhouse-Geisser F (4.875, 370.504) = 211.043, p< .01), semantics*stimuli (Greenhouse-Geisser F (1.623, 123.331) = 8.510, p< .01), and runs*semantics*stimuli (Greenhouse-Geisser F (5.355, 406.969) = 60.948, p< .01). These effects of significant interactions indicated that participants made significantly more errors with abstract stimuli in earlier runs. Participants made more errors in earlier runs with influences from different types of stimuli; for example, people made significantly more errors with icons in the first run, but in later runs, errors with pictures were significantly more than the rest. People also made significantly more errors with concrete and abstract pictures and icons, and significantly fewer errors with concrete and abstract English words and Chinese characters especially in the earlier runs.

How English speakers made errors was not significantly different from Chinese speakers (i.e., there were no significant main and interaction effects between subjects at p= .05).

Plots about Accuracy

The following two figures (Figures 5.1 and 5.2) are plots about participants' accuracy measures. Since there were no significant main and interaction effects between subjects at p= .05, these plots were not separated by subject groups.

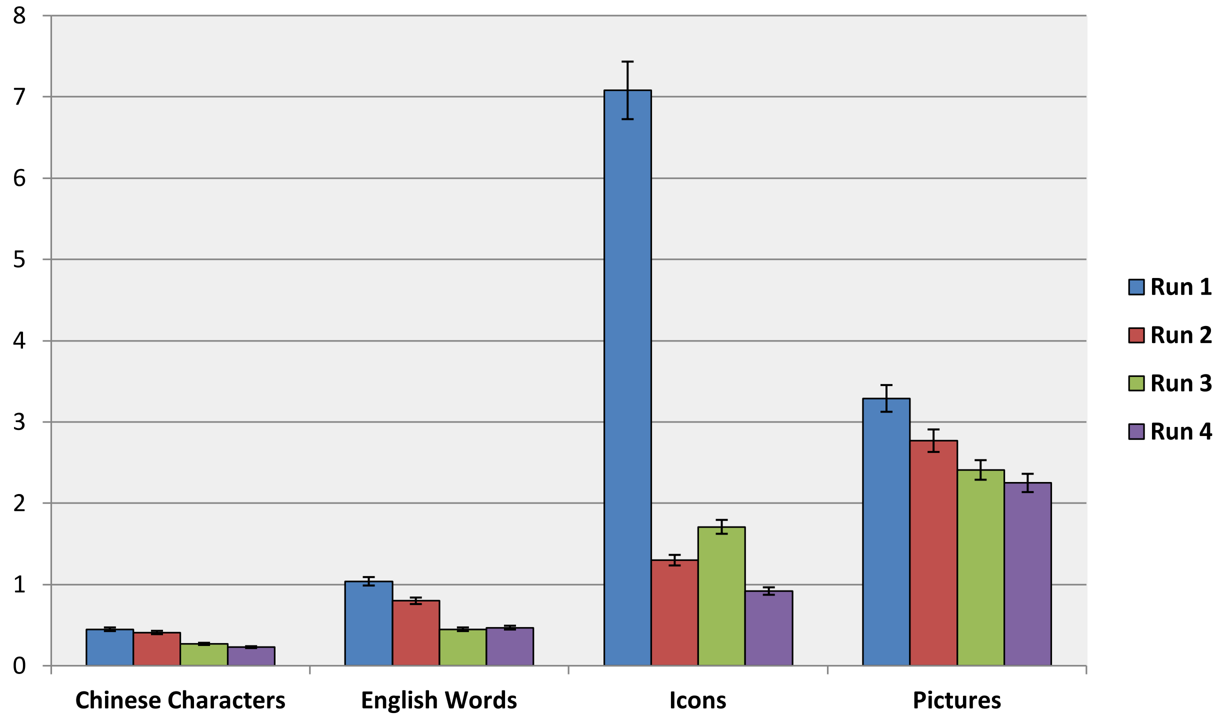


*Figure 5.1 Errors in Runs*Stimuli, All Participants*

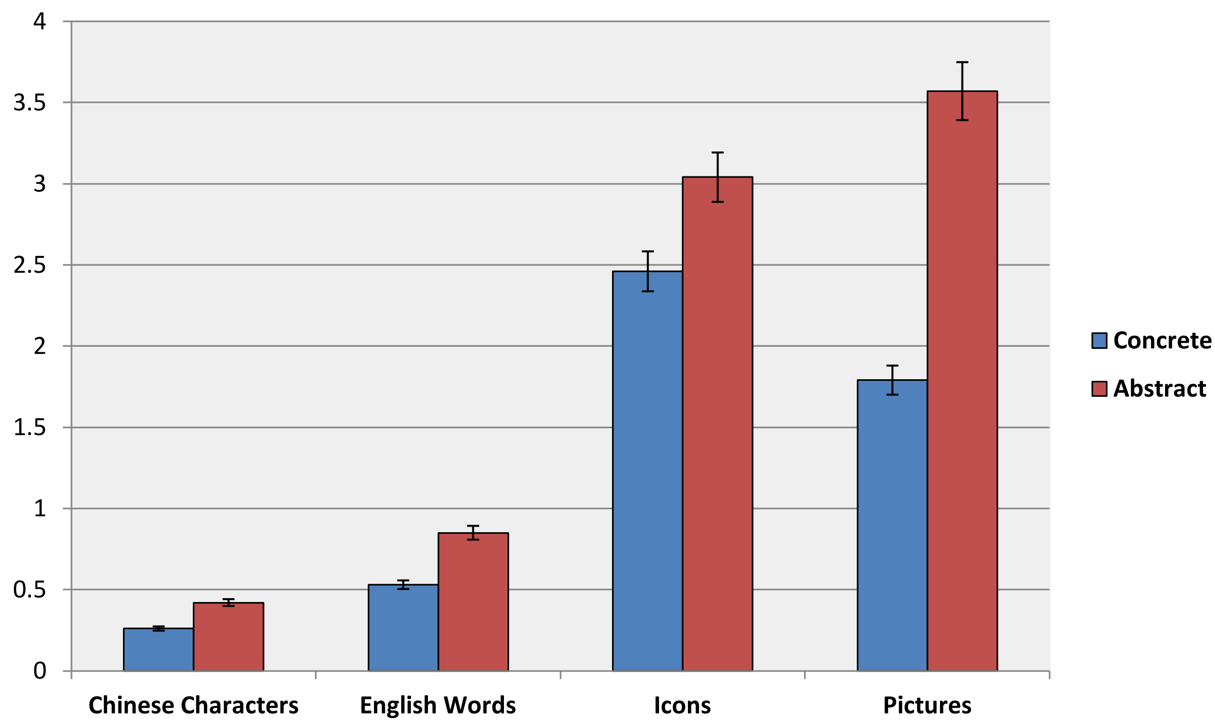


*Figure 5.2 Errors in Semantics*Stimuli, All Participants*

Figure 5.1 shows three findings described in the previous section: 1) participants made significantly more errors with pictures and icons than with English words and Chinese characters, 2) participants made significantly more errors in the first run and significantly fewer errors in later runs, and 3) participants made significantly more errors with icons in the first run in contrast to other types of stimuli.

Figure 5.2 shows two findings described in the previous section: 1) participants made significantly more errors with abstract stimuli, and 2) participants made significantly more errors with pictures and icons, and made significantly fewer errors with English words and Chinese characters in both concrete and abstract categories. Note, in Figure 5.2, the mean difference of errors between icons and pictures was not significant, nor was the mean difference of errors between Chinese characters and English words.

Findings about Efficiency in Performance

There were significant contrasts of reaction times in different experimental runs (Greenhouse-Geisser $F(2.094, 148.667) = 145.838$, $p < .01$), represented semantics ($F(1, 71) = 77.784$, $p < .01$) and types of stimuli (Greenhouse-Geisser $F(2.613, 185.489) = 344.412$, $p < .01$).

Pair-wise comparisons of different experimental runs indicated that participants were significantly slower in the first run (mean = 997.51 milliseconds, significant mean differences in contrast to other runs at $p = .01$) and significantly faster in later runs while reaching their maximum speed in the third and the fourth run (mean = 872.029 milliseconds and 864.228 milliseconds, significant mean differences in contrast to run 1 and 2 at $p = .01$). Pair-wise comparisons of different represented semantics indicated that participants responded significantly slower with abstract stimuli (significant mean difference = 80.279 milliseconds at $p = .01$). Given the decision not to counterbalance particular finger used to map the semantic categories, concrete vs. abstract, this finding of speed differences is reserved for further examinations. Pair-wise comparisons of different types of stimuli indicated that participants spent significantly longer time interpreting pictures (mean = 1029.028 milliseconds) than icons (mean = 966.845 milliseconds); followed by the order of English words (mean = 923.226 milliseconds), and Chinese characters (mean = 772.647 milliseconds) at $p = .01$.

There were significant interactions in runs*semantics (Greenhouse-Geisser $F\ (2.403, 170.616) = 35.039$, $p < .01$), runs*stimuli ($F\ (9, 639) = 24.458$, $p < .01$), semantics*stimuli (Greenhouse-Geisser $F\ (2.585, 183.563) = 25.09$, $p < .01$), and runs*semantics*stimuli (Greenhouse-Geisser $F\ (7.324, 520.024) = 25.741$, $p < .01$). These effects of significant interactions indicated that participants were significantly slower with abstract stimuli in earlier runs and such a pattern persisted even though they had improved performance in later runs. (This is likely due to people's relative facility with pressing a button with the index finger. See discussions in the later section.) Participants were also slower in earlier runs with influences from different types of stimuli in a pattern of spending more time interpreting pictures than icons, English words, and Chinese characters. Participants also needed significantly more time with abstract pictures and abstract icons, and significantly less time with concrete English words and Chinese characters.

The main effect between subject groups was not significant at $p=.05$, but there were significant interaction effects between subjects regarding different types of stimuli. In this case, significant interactions were found in stimuli*subjects ($F\ (3, 213) = 58.081$, $p < .01$), runs*stimuli*subjects ($F\ (9, 639) = 3.209$, $p < .01$), runs*semantics*stimuli*subjects ($F\ (9, 639) = 3.563$, $p < .01$). These significant between-subject effects indicated that English speakers responded significantly faster with Chinese characters than Chinese speakers regardless of different conditions of runs and/or semantics. This significant efficiency was because Chinese characters served as meaningless stimuli to English speakers who were not required to perform semantic interpretations between concrete and abstract conditions. English speakers' responses to Chinese characters thus needed less cognitive load and were behaviorally faster.

Plots about Efficiency

The following two figures (Figures 5.3 and 5.4) are plots about participants' efficiency measures. Since there were significant interaction effects between subjects at p = .01, these plots were separated by subject groups.

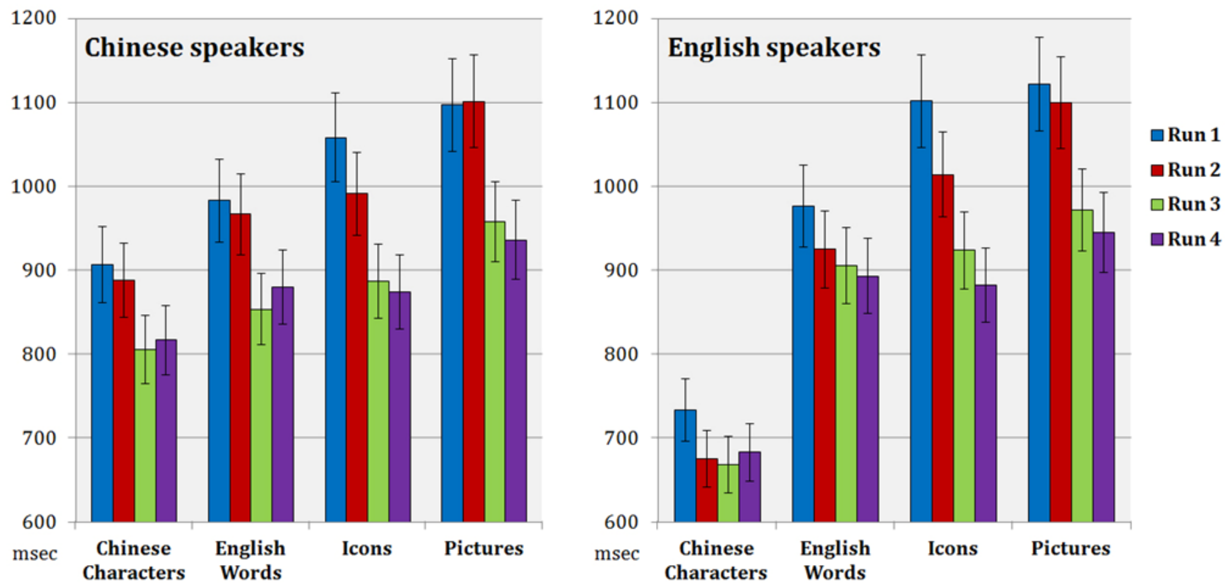


*Figure 5.3 RTs in Runs*Stimuli, Chinese and English Participants*

Figure 5.3 shows that: 1) participants spent significantly longer time interpreting pictures than icons, followed by English words and Chinese characters in that order; 2) participants performed significantly slower in the first run and improved significantly in later runs, and 3) English-reading participants were on average, significantly faster than Chinese-reading participants because they responded significantly faster with Chinese characters in all runs.

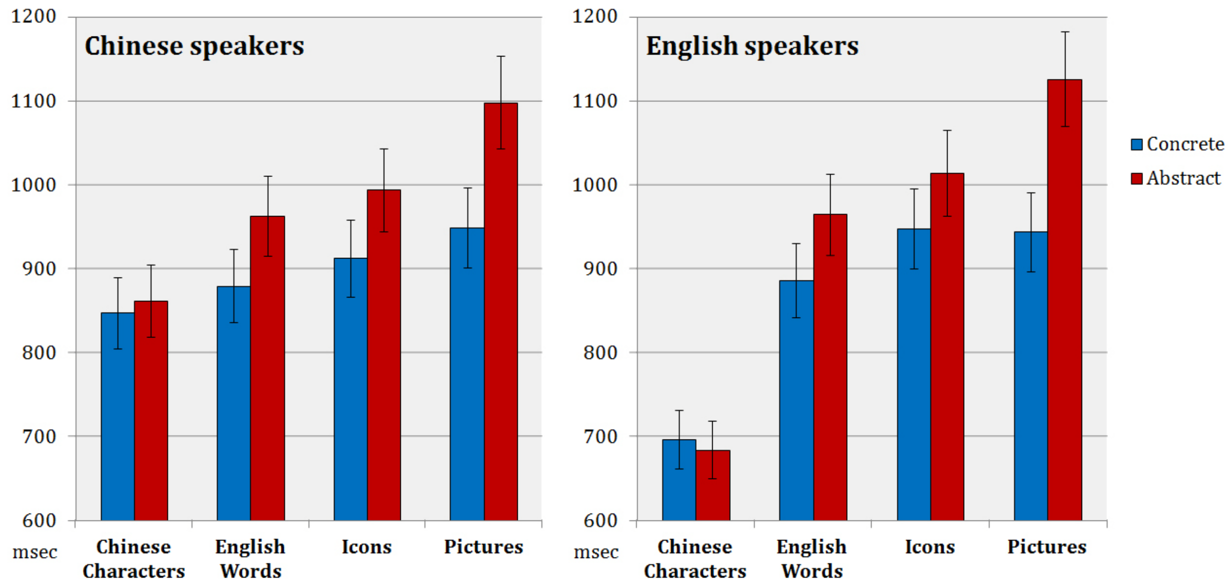


*Figure 5.4 RTs in Semantics*Stimuli, Chinese and English Participants*

Figure 5.4 shows that: 1) participants needed significantly more time with abstract stimuli across all types of stimuli; 2) participants needed significantly more time with abstract pictures and abstract icons, and significantly less time with concrete English words and Chinese characters, and 3) English-reading participants were on average, significantly faster than Chinese-reading participants because they responded significantly faster with Chinese characters. This is probably because they were not required to perform semantic interpretations between concrete and abstract conditions of Chinese characters.

Findings and Discussion

Key Findings and Implications

The second study had three key findings: 1) people performed worst with icons in terms of accuracy and efficiency when they were introduced to a set of icons for the first time with little support of context, 2) people spent more time and made more mistakes in interpreting abstract stimuli than concrete stimuli, and 3) people spent more time and made more mistakes in interpreting graphical information (pictures and icons) than with textual information(English words and Chinese characters) in both concrete and abstract categories.

In the analysis of errors, participants' average error rate was lower than five percent on average, which implied that these 200 stimuli selected from Study One were indeed well representative of the two semantic categories, concrete and abstract, and participants complied with the statistical norms in Study One. Abstract stimuli remained more difficult for participants to correctly interpret their meanings (Figure 5.2). Participants' error counts dropped significantly after the first run. This reflects a learning effect showing that participants were adapting to the behavioral task rapidly (Figure 5.1). However, the analysis of errors also found that participants made significantly more errors in interpreting icons in the first run in contrasts to other stimuli (Figure 5.1), which implied that icons might be the most unfamiliar form of semantic representations of objects and concepts to people when they were first introduced. Moreover, with only a few runs, participants' semantic interpretations with icons were significantly improved; although errors made with icons became slightly fewer than with pictures and remained significantly more than texts in both languages. Therefore, in terms of participants' accuracy in semantic interpretation, icons were still much like pictures and not as effective as texts.

Similar findings could also be identified in the analysis of reaction times where participants' speed improved significantly in later runs (Figure 5.3), which showed the effects of task learning and skill retention. Abstract stimuli remained more difficult for participants to efficiently interpret (Figure 5.4), which implied that a concept representation required longer processing time in human cognition than an object representation. However, even concrete pictures and icons were harder than concrete texts for the participants to interpret. The analysis of reaction times also revealed that participants could respond significantly faster with icons than pictures but remained significantly slower with icons than texts in both languages on average (Figure 5.3 and 5.4). Therefore, in terms of participants' efficiency in semantic interpretation, icons are slightly better than pictures but not as significantly effective as texts in this behavioral task.

Limitations and Controls

Participants' inferior accuracy and efficiency with pictures and icons might be due to their unfamiliarity with the stimuli in contrast to the much familiar texts that are used more frequently. Accordingly, reliable controls were employed on this factor of unfamiliarity by carefully selecting highly-comprehensive pictures and icons in both concrete and abstract categories by their normative ratings in Study One. These stimuli were posed as well-designed samples and proved to be easier and less ambiguous for participants to interpret during the experiment of this study (the participants' average error rate in performance was lower than five percent). Also, the experiment was design with four runs and the learning effect of participants' improvement in performance was observed in later runs. The learning improvement reduced such unfamiliarity, but the effect of stimuli factor still remained and people still perform worse with pictures and icons than texts in later runs.

People's index fingers (169±28 msec) usually respond faster than middle fingers (177±34 msec) (Aoki et al., 2003), and errors related to motor switches between these two fingers might systematically affect measures in efficiency and accuracy of Study Two. Such potential confounds in such a finger-response mapping in the experimental design were controlled by inserting ten percent null conditions in every run. Participants were asked not to respond to these null conditions, and errors and reaction times of such null conditions were not counted in the analyses of speed. These null conditions gave random pauses to participants to prevent them from being habituated to a certain finger movement that might increase switch errors, and provided a balancing mechanism for different speeds of the index and middle fingers by re-initiating the motor responses. In addition, English speakers' middle finger speed under Chinese character condition was significantly faster than under other conditions (Figure 5.4 and 5.5). This provided further support to the idea that the speed difference between the index and middle finger (estimate mean, 8 msec) was not the main effect contributing to the significant speed difference between responses of interpreting concrete and abstract stimuli (80.279 ms), and it would suggest that such a speed difference was caused by the IV (F2).

Conclusion

Under the experimental conditions of this study, participants did not read icons as words in terms of accuracy and efficiency in performance. Similar to interpreting pictures, reading icons was slower and was prone to more errors than reading single words especially when such graphical symbols were introduced to readers for the first time. With repeated exposure and retention, test participants could correctly interpret icons faster than pictures in later runs, but participants still performed the task the best with their native languages. Findings of Study Two imply that even well-selected icons are fundamentally inferior to single words to effectively and efficiently convey the immediate semantics of objects and concepts in terms of people's accuracy and efficiency in performance. Such results challenge the conventional HCI literatures (e.g., Caplin, 2001; Horton, 1994, and Pedell, 1996) that suggest icons can provide more effective and efficient communication and universal interpretations without the support of localized texts. Study Two also agrees with the work of Haramundanis (1996), Kim and Lee

(2005), Walton et al. (2002), Wang (2007), and Wiedenbeck (1999) suggesting that icon recognition requires additional visual or interactive aids to achieve better user performance.

This study was undertaken as one in a series of three studies to understand how humans behaviorally process icons. In the first study, survey data from a sample of 211 subjects provided an empirical understanding of whether people interpreted certain stimuli as representing “concrete” objects or “abstract” concepts. Study Three gathered fMRI data while test participants made semantic judgments (concrete vs. abstract) upon icons in contrast to other visual stimuli. This middle study was the behavioral study, designed to collect performance data of such semantic judgments. The data from Study Two help guide the understanding of which types of visual stimuli are harder or easier for humans to read and judge. The data also provide corroborating evidence when compared with the subsequent fMRI data. Findings of these three studies will afford a better understanding of human factors in people’s semantic interpretations of various types of visual information.

In conclusion, results of Study Two demonstrated that there was a fundamental difference in people’s accuracy and efficiency between interpreting graphical information and textual information. People made a lot of mistakes with icons when they saw them for the first time, and like pictures, people made a lot of mistakes with icons, especially with abstract ones. Icons do a bit better job than pictures, but are far worse than texts. In addition, even concrete icons take people more time to respond than concrete words. Such findings contribute to better understanding of human factors in interactive information and design, and the role of graphical and textual information in human activities that involve the use of social media that use symbols and texts to interface communication: independently, icons are not as accurate and efficient as texts in terms of conveying specific meanings.

Chapter Six: Study Three—Neuroimaging Measures of Semantic Interpretations

Experimental Design

Study Three was designed to investigate how people utilize different cortical regions in the brain to interpret meaningful symbols such as icons in contrast to other types of visual information including pictures, single English words, and single Chinese characters.

Participants

Twenty subjects who had better performance in their behavioral data among the 78 participants in Study Two were selected to participate in Study Three. These participants included the top 10 Chinese and 10 English speakers from the 78 participants in Study Two to form two groups. The number of subjects met the statistical requirement of sample size for an event-related design in experiment and group analysis of fMRI studies (cf. Desmond & Glover, 2002; Murphy, & Garavan, 2004). Each group had five males and five females to control the gender factor that was related to language processing (cf. Kaiser et al., 2009). All 20 participants had to be right-handed and within the age range of 18 to 35 years old. Such screening was to control the factors of handedness and age (cf. Knecht et al., 2000; Fridriksson et al., 2006). These 20 participants were also screened to make sure that they had normal or corrected vision and did not have histories of mental illnesses, neurological diseases or head injuries. Additional procedures and screening tests for the safety of fMRI research are also described in details in the Appendixes F and G according to the regulations of the Institutional Review Board (IRB) and the standard operating procedure of the Imaging Research Center (IRC) at the University of Texas at Austin for conduct of human subject research in fMRI studies.

Test Materials, fMRI Paradigm, and Behavioral Task

Study Three used the same 200 stimuli from Study Two. Study Three also used the same experimental design for the presentation of stimuli, behavioral tasks, and behavioral measures from Study Two (see Chapter Five).

fMRI Acquisition Method

Functional imaging was acquired by a General Electric 3.0 Tesla Magnetic Resonance Imaging (MRI) scanner (Repetition Time [TR] =2 sec) using a multi-echo generalized autocalibrating partially parallel acquisitions (GRAPPA) parallel imaging with echo-planar imaging (EPI) sequence at the Imaging Research Center at the University of Texas at Austin. The multi-echo GRAPPA parallel imaging EPI sequence is developed at Stanford and optimizes BOLD signals in regions of medial frontal cortex that are typically vulnerable to susceptibility artifact. Functional EPI images were collected utilizing whole head coverage with slice orientation to reduce artifact (approx 20 degrees off the AC-PC plane [referential to the Anterior and Posterior Commissures], TR = 2 sec., 3 shot, Echo Time [TE] = 30 msec., 35 axial slices oriented for best whole head coverage, acquisition voxel size = 3.125 x 3.125 x 3 mm with a .3 mm inter-slice gap). The first four EPI volumes were discarded to allow scans to reach equilibrium. In all cases, the presentation of stimuli was viewed utilizing a back projection screen and a mirror mounted on the top of the head coil. Responses were collected using a MR-compatible two-button response pad that was held in the right hand. In addition to obtaining EPI images during task performance, one or two high-resolution T1 SPGR (spoiled gradient recalled) scans that had been empirically optimized for high contrast between grey matter (GM) and white matter (WM), and GM and cerebrospinal fluid (CSF) were acquired. These images were acquired in the sagital plane using a 1.3-mm slice thickness with 1 mm in plane resolution.

Analysis and Results

Data Validation

Behavioral and fMRI data were acquired at the Imaging Research Center at the University of Texas at Austin with participants selected from Study Two from November 12th to December 2nd, 2010. The functional imaging data of one female Chinese participant were not included in the final analysis due to her excessive head movements (i.e. coughing) in the scanner during the experimental process.

Data Analysis

The same statistical analyses in Study Two were used to analyze the behavioral data of Study Three to see if the participants' behavioral responses were in agreement with findings of Study Two.

FMRI analysis was carried out using FEAT (FMRI Expert Analysis Tool) Version 5.63 with an "uncorrected" stats threshold with a $p < .01$ in each subject. In agreement with the experimental design of the fMRI paradigm, each participant's functional imaging data consisted of four runs. Excluding all error and null trials, these four runs were combined and normalized as one participant's data. Ten English speakers' data were again combined and normalized as the English group's data, and the same process was applied to the nine Chinese speakers' data. These normalized imaging data were analyzed to determine critical BOLD contrasts within and between each group, respectively, in the following 13 fMRI analyses:

1. Interpreting overall different semantics—this analysis is to identify neural correlates of participants when they are correctly interpreting both concrete and abstract stimuli regardless of the types of visual information.

2. Interpreting concrete stimuli—this analysis is to identify neural correlates of participants when they are correctly interpreting concrete stimuli.
3. Interpreting abstract stimuli—this analysis is to identify neural correlates of participants when they are correctly interpreting abstract stimuli.
4. Concrete vs. abstract—this analysis is to identify neural correlates of interpreting concrete stimuli that are significantly different from interpreting abstract stimuli.
5. Abstract vs. concrete—this analysis is to identify neural correlates of interpreting abstract stimuli that are significantly different from interpreting concrete stimuli.
6. Interpreting overall different types of stimuli—this analysis is to identify neural correlates of participants when they are correctly interpreting all four types of visual information.
7. Interpreting icons—this analysis is to identify neural correlates of participants when they are correctly interpreting icons.
8. Icons vs. Chinese characters—this analysis is to identify neural correlates of interpreting icons that are significantly different from interpreting Chinese characters.
9. Chinese characters vs. icons—this analysis is to identify neural correlates of interpreting Chinese characters that are significantly different from interpreting icons.
10. Icons vs. English words—this analysis is to identify neural correlates of interpreting icons that are significantly different from interpreting English words.
11. English words vs. icons—this analysis is to identify neural correlates of interpreting English words that are significantly different from icons.

12. Icons vs. pictures—this analysis is to identify neural correlates of interpreting icons that are significantly different from interpreting pictures.
13. Pictures vs. icons—this analysis is to identify neural correlates of interpreting pictures that are significantly different from interpreting icons.

FEAT analyses of these BOLD contrasts within and between Chinese and English participants were applied to determine whether fMRI data modulated by the experimental condition of interpreting icons shared greater similarities with logograms than with pictures within the same semantic system of the brain. The overall experimental conditions were presumed to have modulated activations of the overall semantic system in the brain. Modulated activations of icons versus logograms/words were presumed to be similar in terms of overlapping distributions of BOLD contrasts in Talairach coordinates, whereas modulated activations of icons versus pictures were presumed to have a greater difference than those of icons versus logograms/words in terms of demarcating distributions of BOLD contrasts in Talairach coordinates.

Behavioral Data about Errors

There were significant contrasts in numbers of errors in within-subject factors including different experimental runs ($F(3, 54) = 102.363$, $p < .01$), represented semantics ($F(1, 18) = 8.214$, $p < .05$), and types of stimuli ($F(3, 54) = 148.043$, $p < .01$).

Pair-wise comparisons of different experimental runs indicated that participants made significantly more errors in the first run (mean = 2.194, significant mean differences in contrast to all other runs at $p = .01$) and significantly fewer errors in the fourth run (mean = .544, significant mean differences in contrast to all other runs at $p = .01$). The difference between the second and the third run's mean error was not significant at $p = .05$, but their mean errors were both significantly fewer than the first run and significantly more than the fourth run ($p<.01$). Pair-wise comparisons of different represented semantics indicated that participants made significantly more errors with abstract stimuli (significant mean difference = .559 at $p= .05$). Pair-wise comparisons of different types of stimuli indicated that people made significantly more errors with icons (mean = 2.752, significant mean differences in contrast to all other runs: 1.944 more than Chinese characters, 1.750 more than English words, and .475 more than pictures at $p= .01$) and pictures (mean = 2.681, significant mean differences in contrast to all other runs: 1.469 more than Chinese characters, 1.275 more than English words and .475 fewer than icons at $p= .01$). The mean difference between errors made with Chinese characters and English words was not significant at $p= .05$.

There were significant interactions in runs*semantics ($F(3, 54) = 12.952$, $p< .01$), runs*stimuli (Greenhouse-Geisser $F(2.839, 51.107) = 99.262$, $p< .01$), and runs*semantics*stimuli (Greenhouse-Geisser $F(4.176, 78.166) = 24.695$, $p< .01$). These effects of significant interactions indicated that participants made significantly more errors with abstract stimuli in earlier runs. Participants made more errors in earlier runs with influences from different types of stimuli. For example, participants made significantly more errors with icons in the first run, and in later runs, errors with pictures were significantly more than the rest. Participants also made significantly more errors with concrete/abstract pictures and icons, and significantly fewer errors with concrete/abstract English words and Chinese characters especially in the earlier runs.

The main effect between subject groups was significant ($F(1, 18) = 6.385$, $p< .05$), and there were significant interaction effects between subjects regarding different types of stimuli. In this case, significant interactions were found in stimuli*subjects ($F(3, 54) = 8.008$, $p< .01$).

Chinese speakers made significantly more errors with Chinese characters than English speakers. This significant difference was not critical since English speakers did not interpret meanings of Chinese characters.

In conclusion, participants' behavioral data of errors were consistent with findings of Study Two. Since the data of errors would be excluded and not reflected in the fMRI analyses, the purpose of this analysis of participants' behavioral data was mainly to show that participants' behavioral responses did not change significantly from the previous study.

Behavioral Data about Reaction Times

There were significant contrasts of reaction times in all within-subject factors including different experimental runs ($F (3, 54) = 67.385$, $p< .01$), represented semantics ($F (1, 18) = 9.509$, $p< .01$) and types of stimuli ($F (3, 54) = 110.073$, $p< .01$).

Pair-wise comparisons of different experimental runs indicated that participants were significantly slower in the first run (mean = 1004.136 milliseconds, significant mean differences in contrast to all other runs at $p= .01$) and significantly faster in later runs, reaching their maximum speed in the third and the fourth runs (mean = 871.667 milliseconds and 863.903 milliseconds, significant mean differences in contrast to run 1 and 2 at $p= .01$). Pair-wise comparisons of different represented semantics indicated that participants responded significantly slower with abstract stimuli (significant mean difference = 44.164 milliseconds at $p= .01$). Pair-wise comparisons of different types of stimuli indicated that participants spent significantly longer time interpreting pictures (mean = 1016.980 milliseconds) than all other types stimuli at $p=.01$. Interpreting icons (mean = 948.801 milliseconds) was significantly faster than pictures and significantly slower than Chinese characters at $p= .01$. Interpreting English words (mean = 933.317 milliseconds) was also significantly faster than pictures and significantly slower than Chinese characters at p= .01. Interpreting Chinese characters (mean = 801.603 milliseconds) was significantly faster than all other types of stimuli at p= .01.

There were significant interactions in runs*semantics (F (3, 54) = 3.888, p< .05), runs*stimuli (F (9, 162) = 11.578, p< .01), semantics*stimuli (F (3, 54) = 5.170, p< .01), and runs*semantics*stimuli (F (9, 162) = 4.938, p< .01). These effects of significant interactions indicated that participants made significantly more errors with abstract stimuli in earlier runs. Participants made more errors in earlier runs with influences from different types of stimuli; for example, people made significantly more errors with icons in the first run, and in later runs, errors with pictures were significantly more than the rest. People also made significantly more errors with concrete/abstract pictures and icons, and significantly fewer errors with concrete/abstract English words and Chinese characters, especially in the earlier runs.

The main effect between subject groups was significant (F (1, 18) = 11.283, p< .01), and there was a significant interaction in stimuli*subjects (F (3, 54) = 15.924, p< .01). This indicated that English speakers responded significantly faster with Chinese characters than Chinese speakers regardless of different conditions of runs and/or semantics. This significant efficiency was because Chinese characters served as meaningless stimuli to English speakers who were not required to perform semantic interpretations between concrete and abstract conditions. English speakers' responses to Chinese characters thus needed less cognitive load and were behaviorally faster.

In conclusion, participants' behavioral data of reaction times were consistent with findings of Study Two.

FMRI data processing was carried out using FEAT (FMRI Expert Analysis Tool) Version 5.98, part of FSL (FMRIB's Software Library, www.fmrib.ox.ac.uk/fsl). Z (Gaussianised T/F) statistic images were thresholded using clusters determined by Z>2.3 and a (corrected) cluster significance threshold of P=0.01 (Worsley, 2001). Significant activations in brain regions are identified according to 1) Harvard-Oxford Cortical Structural Atlas, and 2) Talairach Daemon Labels provided by fslview. The following sections only present fMRI contrasts that are critical to the major findings of this dissertation. Detailed descriptions of all 13 analyses are presented in Appendix C.

fMRI Analysis: Utilization of the Language-based Semantic System

The overall utilization of the language-based semantic system in the brain was observed in both English and Chinese speakers under conditions of sorting these four different types of stimuli into concrete and abstract categories. Brain regions suggested by Binder et al. (2009) were identified in significant fMRI contrasts (Z>2.3). For example, Figure 6.1 shows significant clusters that are related to the overall modulated activations of the the language-based semantic system under that condition of English words vs. icons with Chinese participants.

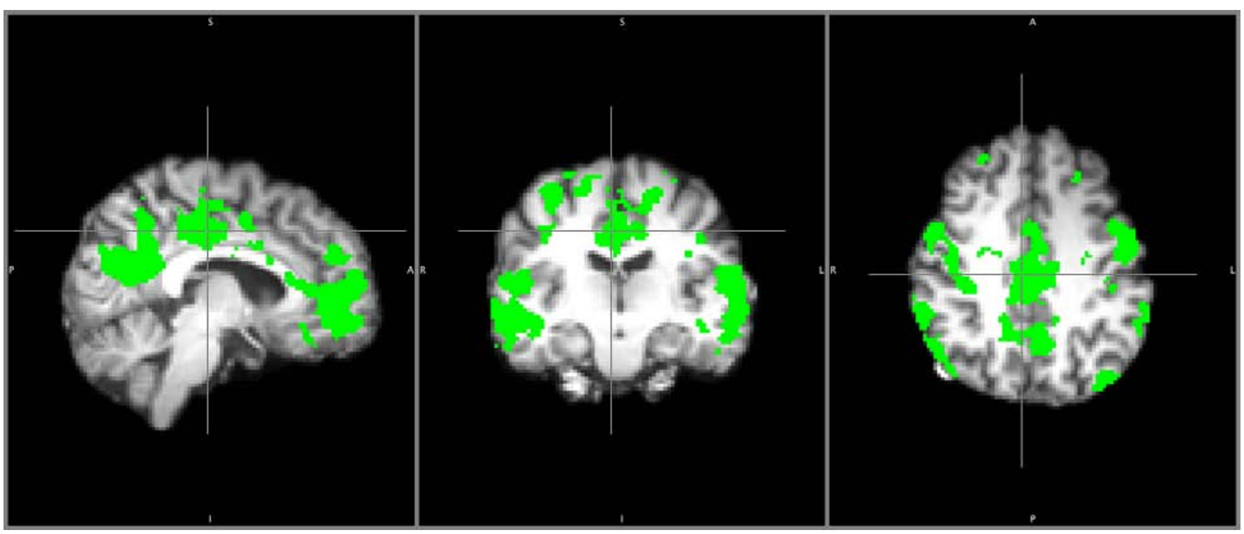


Figure 6.1 Overall Modulated Activations of the Language-based Semantic System

FMRI contrasts of within and between group analyses under different conditions revealed significant proportions of activated brain regions including the AG in both hemispheres, bilateral posterior division of the SMG, both bilateral posterior division and temporooccipital part of the MTG, right posterior division of the Cingulate Gyrus, inter-hemisphere areas of the DMPFC and the VMPFC, right parietal operculum cortex, both pars triangularis and pars opercularis of the IFG and its surrounding areas like the MFG and the Frontal Pole in both hemispheres, the Temporal Occipital Fusiform Cortext and the posterior division of the Temperoal Fusiform Cortex in both hemispheres, and Brodmann area 2, 3, 4, 6, 7, 8, 9, 10, 13, 17, 18 19, 20, 21, 22, 23, 30, 31, 32, 37, 38, 39, 40, 43, 45, 46, and 47 (see Appendix C for details). These observed areas were in agreement with the activation of foci of semantic contrasts in the meta-analysis of Binder et al. (2009) (see Figure 2.3 and 2.4) and the proposed brain regions involved in language processing according to Démonet et al. (2005) (see Figure 2.2). Such findings implied that participants were in general utilizing the language-based semantic system in the brain in order to successfully complete the experimental task.

fMRI Analysis: Comparisons between English and Chinese Speakers

Within-group analyses revealed that there was a certain brain region critical to participants to sort these stimuli into concrete and abstract categories: left IFG for English speakers and left SMG for Chinese speakers. Figure 6.2 shows modulated activations in the left IFG of English speakers under the condition of interpreting icons and Figure 6.3 shows modulated activations in the left SMG of Chinese speakers under the same experimental condition.

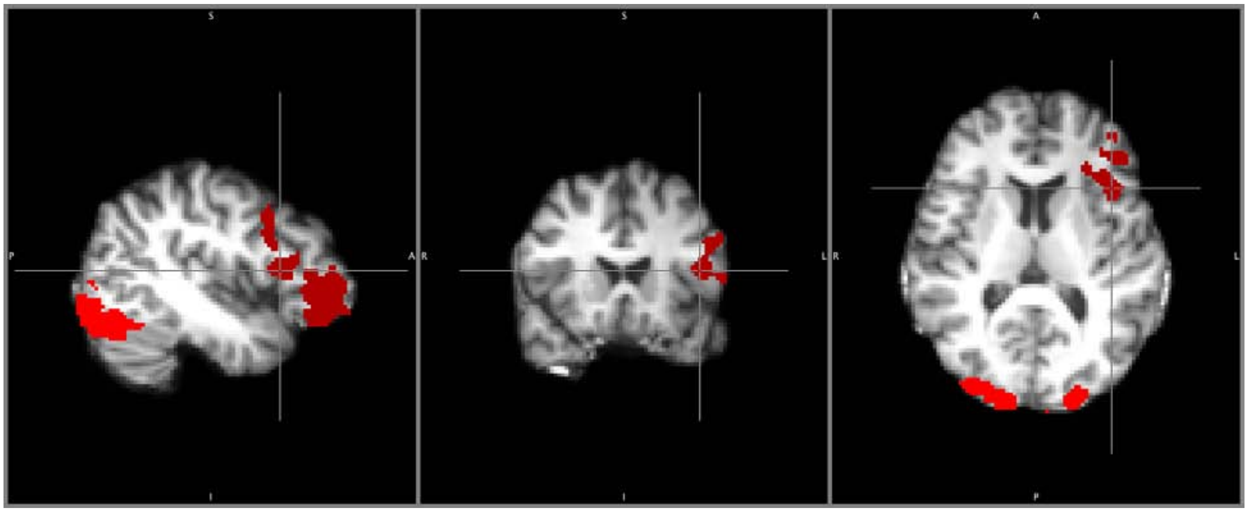


Figure 6.2 Modulated Activations in the Left IFG of English Speakers

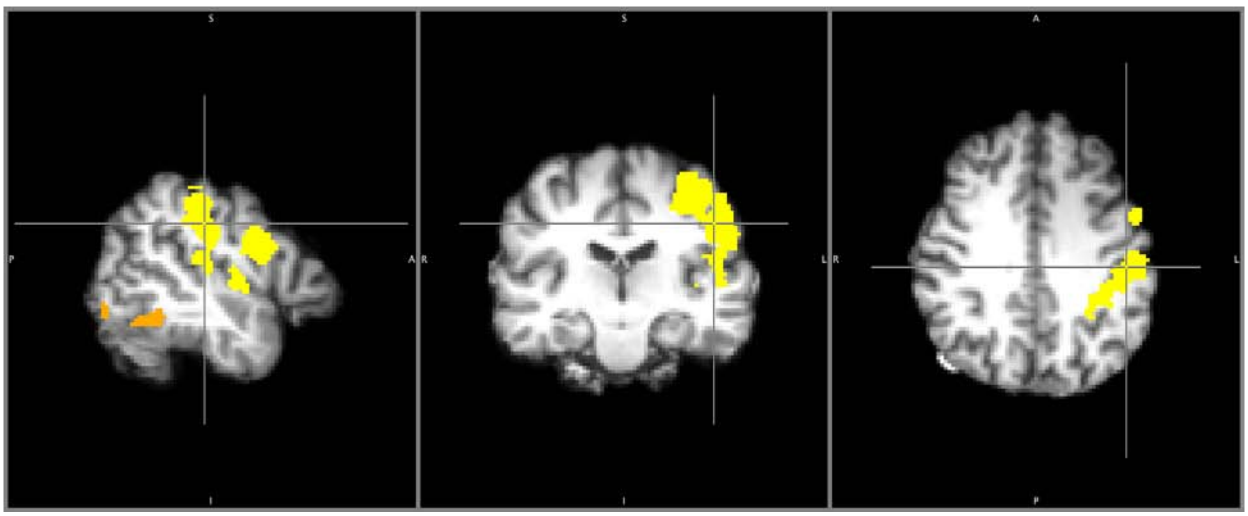


Figure 6.3 Modulated Activations in the Left SMG of Chinese Speakers

Similar modulated activations could also be observed in other within-subject analyses across all 13 analyses with some variances of other accompanying brain regions that were significantly activated in fMRI contrasts. English speakers would often have accompanying activations in the left MFG and the left Frontal Pole besides the left IFG, while Chinese speakers would have accompanying activations in the bilateral IFG besides the left SMG. The left IFG and the left SMG are two brain areas critical to human language processing that have been discussed in both the classic model and the modern framework of languge representations in the brain (Kandel et al., 2000) (see Figure 2.1). The significant contrasts in these two regions could imply that participants might be generating words in order to successfully complete the experimental task.

Despite an apparently different pattern of excitations in the brain between the left IFG and the left SMG, between-group analyses did not find significant differences in fMRI contrasts between English and Chinese speakers that were critical to the semantic processes of sorting these four types of stimuli into concrete and abstract categories. Most significant differences in fMRI contrasts in between-group analyses were found in the primary visual and motor cortexes that were responsible for perceptual and behavioral processes of the experimental task. However, there was one exception: when contrasting fMRI data under icons vs. Chinese charaters or vice versa, there were significant fMRI contrasts between Chinese and English speakers in the right hemisphere that involved modulated activations in the AG, the temporooccipical part of the MTG, the MFG, and the IFG. This might imply that these brain areas in the right hemisphere were critical to the visual processing of Chinese characters regardless of whether the test participants understood the meanings of Chinese characters or not. Such findings were in agreement with Yoon et al. (2006) about the possibility of a right hemispheric dominance within the occipito-temporal and the left middle/medial frontal area for both reading Chinese characters and naming pictures.

fMRI Analysis: Comparisons between Icons, Pictures, and Chinese Characters

FMRI contrasts among conditions of interpreting icons, pictures, and Chinese characters indicated that there were significant differences between icons and Chinese characters whereas there was no dignificant difference between icons and pictures in BOLD signals at Z>2.3. Figure

6.4 and 6.3 show Chinese and English speakers' fMRI contrasts under these experimental conditions.

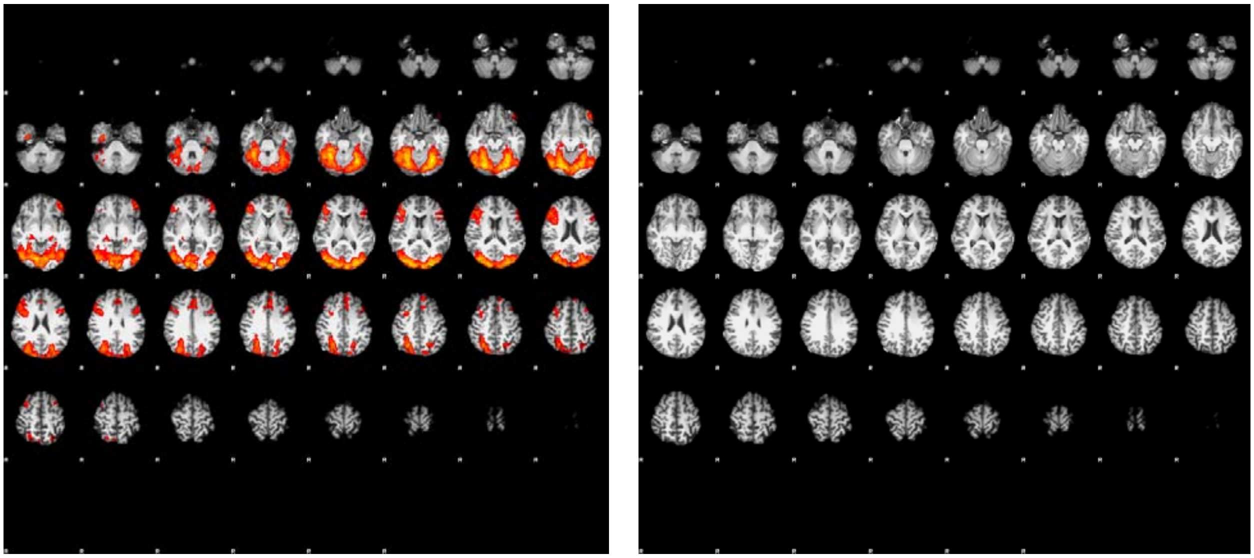


Figure 6.4 Left: Chinese Speakers under Icons vs. Chinese Characters; Right: Icons vs. Pictures

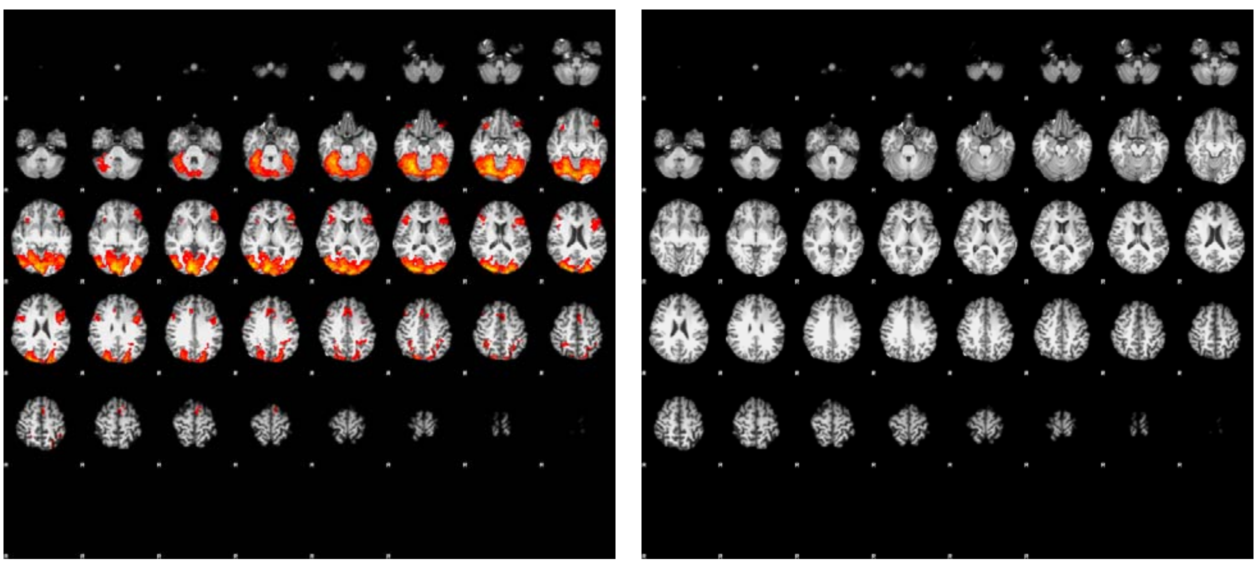


Figure 6.5 Left: English Speakers under Icons vs. Chinese Characters; Right: Icons vs. Pictures

Despite the fact that English speakers could not understand the meaning of Chinese characters, their fMRI contrast showed similar pattern as the Chinese speakers' under the condition of icons vs. Chinese characters. Modulated activations in the IFG and the Frontal Pole in both hemispheres were identified in both English and Chinese speakers with additional activations in the left DMPFC and VMPFC of Chinese speakers. Such modulated activations might imply that the phonological processing was an essential mechanism to compare icons and Chinese characters in the experimental task, and Chinese speakers might be more motivated and have better sustained attention than English speakers during this comparison. In addition, like the previous session mentioned, between-group analysis under icons vs, Chinese characters revealed that the IFG, the MFG, the AG, and the MTG in the right hemisphere were critical to the visual processing of Chinese characters. Because of these significant fMRI contrasts between icons and Chinese characters, it implied that the cognitive mechanism of interpreting icons was different from interpreting Chinese characters in the task of sorting them into concrete and abstract categories.

On the other hand, there was no significant difference in BOLD signials under the condition of icons vs. pictures in both Chinese and English speakers' fMRI contrasts at Z>2.3. There was also no significant difference in between-group analysis under this condition. Such results implied that the cognitive mechanism of interpreting icons might be similar as interpreting pictures in the experimental task.

Findings and Discussion

Key Findings and Implications

Key findings of this study can be categorized into three results based on the fMRI data:

1. There were modulated activations in the left IFG and the left SMG suggesting that participants were generating words while doing the cognitive task of concrete vs. abstract judgment regardless of the types of visual information.

2. There were also modulated activations in the brain that were associated to the left-lateralized (but not restricted to such a lateralization) network of language-based semantic processing while participants were interpreting all four types of visual information.
3. In the within-subject analysis, the modulated activations were found in the left IFG of English speakers and in the left SMG of Chinese speakers, but there were no modulated contrasts in the between-subject analysis. These analyses suggested that English and Chinese speakers might use the language-based semantic system in the same way but with different emphases in these two brain regions. In addition, such modulated activations were also influenced by the types of visual information, indicating that the process of interpreting meanings of icons was less complicating than interpreting pictures, and significantly different from single English word or Chinese character processing.

Table 6.1 summarizes critical regions under concrete vs. abstract conditions, and Table 6.2 summarizes critical regions under conditions of interpreting different types of stimuli from the 13 analyses of fMRI contrasts.

A (overall) CH: L. ad. SMG + o. IFG EN: L. MFG + IFG + FP CH-EN: n/a EN-CH: prime V	**B** Concrete	**C** Abstract
B Concrete	**B*** CH: L. ad. SMG + o. IFG EN: L. MFG + IFG + FP CH-EN: n/a EN-CH: prime V	**C-B** CH: R. IFG + MFG; L. SFG + FP EN: L. IFG + SFG + FP + TP Bi. DMPFC + VMPFC CH-EN: n/a EN-CH: n/a
C Abstract	**B-C** CH: n/a EN: n/a CH-EN: n/a EN-CH: n/a	**C*** CH: L. ad. SMG + t. IFG + FP EN: L. MFG + IFG + FP CH-EN: R. ad. SMG EN-CH: prime V

Table 6.1 Critical Areas Shown in fMRI Contasts in Concrete vs. Abstract Stimuli

A (overall) CH: L. SMG EN: L. IFG CH-EN: n/a EN-CH: n/a	**B** Chinese Characters	**C** English Words	**D** Icons	**E** Pictures
B Chinese Characters			**D-B** CH: Bi. IFG + FP L. DMPFC + VMPFC EN: Bi. IFG + FP CH-EN: R. AG + to. MTG; R. MFG + IFG EN-CH: n/a	
C English Words			**D-C** CH: R. IFG + MFG + FP EN: R. IFG + MFG + FP CH-EN: prime V EN-CH: prime M	
D Icons	**B-D** CH: R. (AG, pd. SMG, DMPFC, VMPFC); L. pd. CG EN: Bi. (AG, SMG, DMPFC, VMPFC, pd. CG) CH-EN: n/a EN-CH: R. (AG, to. MTG, MFG, IFG)	**C-D** CH: L. DMPFC; Bi. (to. pd. MTG, AG, pd. SMG); R. pd. CG EN: Bi. (to. pd. MTG, AG, pd. SMG, pd. CG) CH-EN: prime V, R. prime M. EN-CH: prime V	**D*** CH: L. SMG EN: L. IFG + MFG CH-EN: n/a EN-CH: n/a	**E-D** CH: R. (IFG, MFG, to. MT, AG, pd. SMG) EN: prime V CH-EN: L. prime M EN-CH: n/a
E Pictures			**D-E** CH: n/a EN: n/a CH-EN: n/a EN-CH: prime M	

Table 6.2 Critical Areas Shown in fMRI Contrasts in Different Types of Stimuli

When contrasting concrete and abstract stimuli in a task of semantic judgment, the left IFG plays a critical role in such a cognitive process according to the fMRI data collected from the participants. The modulated activation of the left IFG was observed in both English and Chinese speakers when they were in conditions of interpreting concrete stimuli (Table 6.1, Cell B*), interpreting abstract stimuli (Table 6.1, Cell C*), and differentiating abstract stimuli from concrete stimuli (Table 6.1, Cell C-B). The left IFG (traditionally labeled as the Broca's area or Brodmann area 45) is associated to the efficiency of language processing, especially of the phonological and syntactic processes of words. It implies that the participants in this experiement rely on such language processes to make concrete vs. abstract judgements regardless of the types of stimuli that are presented to them. Therefore, it is plausible that participants were generating words when they were interpreting meanings of icons and pictures.

Another finding is that interpreting the meanings of abstract stimuli requires a broader network in the brain than with concrete stimuli. This finding is concluded from two subtractions of fMRI data in conditions of 1) contrasting concrete stimuli from abstract stimuli (Table 6.1, Cell B-C), and 2) contrasting abstract stimuli from concrete stimuli (Table 6.1, Cell C-B). In the former contrast, there were no additional modulated activations in brain areas within nor between Chinese and English speakers, whereas in the later contrast, although there were no significant activations between English and Chinese speakers, Chinese speakers require additional resources in the right IFG, the right MFG, the left SFG, and the left Frontal Pole, and English speakers require additional resources in the IFG, the SFG, the Frontal Pole, the Temporal Pole in the left hemisphere, and the DMPFC, the VMPFC in both hemispheres. This finding suggested that abstract stimuli were harder than concrete stimuli for the brain to process in terms of requiring more resources in the neocortex. This finding also agrees with the behavioral data in Study Two showing that abstract stimuli took longer time to be accurately interpreted.

While participants were interpreting all four types of visual information, there were modulated activations in the brain that were associated to the left-lateralized network of language-based semantic processing and several additional areas in the right hemisphere that are symmetrical to those in the left hemisphere. These modulated activations include the STG, the MTG, the Parietal Operculum, the AG, the SMG, the mid Fusiform Gyrus, the IFG, the Frontal Pole, the DMPFC, the VMPFC, and the posterior Cingulate Gyrus. While participants were interpreting all four types of visual information, the left SMG of the Chinese speaker was specifically active while the left IFG of the English speaker was specifically active (Table 6.2, Cell A). Contrasts in the overall condition between Chinese and English participants showed no modulated activations, which suggested that Chinese and English participants were probably using the same network but with different weights in using the left SMG and the left IFG. It implies that Chinese speakers favor information integration while English speakers favor phonological processing in the processes of interpreting all four types of visual information.

Contrasts of imaging data in conditions of different types of visual information revealed that interpreting meanings of icons was different from interpreting English words and Chinese characters, and was similar to interpreting pictures. While interpreting icons, Chinese participants had modulated activations in the left SMG whereas English participants had modualated activations in the left IFG and the left MFG (Table 6.2, Cell D*). Contrasts between Chinese and English speakers while they were interpreting icons showed no modulated activations, which suggested that they might again using a same network with different emphases on information integration and phonological processing (Table 6.2, Cell D*).

Contrasts between conditions of interpreting icons and pictures revealed that 1) Chinese participants required additional resources in the IFG, the MFG, the AG, the SMG, and the MTG in the right hemisphere, and English participants needed additional resources in the primary visual cortex to contrast pictures from icons (Table 6.2, Cell E-D), and 2) both Chinese and English participants had no significantly modulated activations when contrasting icons from pictures (Table 6.2, Cell D-E). This suggested that interpreting icons was not really different from interpreting pictures, and icons were processed within the same but a smaller network of brain areas used to process pictures.

When contrasting icons with Chinese characters (Table 6.2, Cell D-B), interpreting icons required more resources in the IFG and the Frontal Pole bilaterally of both Chinese and English speakers. The Chinese participants seemed to be more motivated since the modulated activations of the left DMPFC and VMPFC were also observed in this contrast. Moreover, in contrast to English speakers, Chinese speakers required more resources in the right hemisphere including areas of the AG, the MTG, the MFG, and the IFG. When contrasting Chinese characters from icons (Table 6.2, Cell B-D), interpreting Chinese characters required more resources in the AG, the SMG, the DMPFC, the VMPFC in the right hemisphere, the left posterior Cingulate Gyrus of Chinese participants, and in the same bilateral areas of English participants. In contrast to English participants, Chinese participants needed no extra resources in the brain in this contrast, while English participants required more resources in the AG, the MTG, the MFG, and the IFG in the right hemisphere to contrast Chinese characters from icons (Table 6.2, Cell B-D). By these two contrasts (Table 6.2, Cell D-B and B-D), it is evidently to say that interpreting icons is different from interpreting Chinese characters in terms of how the brain processes these two types of visual information.

When contrasting icons from English words (Table 6.2, Cell D-C), interpreting icons required more resources in the IFG, the MFG and the Frontal Pole in the right hemisphere of both Chinese and English speakers. There were no major differences between Chinese and English speakers in this contrast where Chinese participants were on average more active in the primary visual cortex, while English participants were on average more active in the primary motor cortex (Table 6.2, Cell D-C). When contrasting English words from icons (Table 6.2, Cell C-D), interpreting English words required more resources in the bilateral activations of the MTG, the AG, the SMG, the left DMPFC, the right posterior Cingulate Gyrus of Chinese participants, and in the bilateral activations of the MTG, the AG, the SMG, the posterior Cingulate Gyrus of English participants. There were again no major differences between Chinese and English speakers in this contrast where both Chinese and English participants were on average more active in the primary visual cortex (Table 6.2, Cell C-D). By these two contrasts (Table 6.2, Cell D-C and C-D), interpreting icons is different from interpreting English words in terms of how the brain processes these two types of visual information.

Limitations and Controls

The fMRI contrasts are based on subtractive methods to identify significant activations of brain areas that are modulated by different experimental conditions. Such subtractive methods can only identify critical brain areas after contrasting fMRI data modulated by experimental conditions but cannot really show the functional connections among these critical brain areas. The purpose of Study Three's analyses of fMRI data is NOT to understand the neural mechanisms of these identified critical areas that are used to interpreting icons, pictures, Chinese characters, and English words, but to use established references in fMRI studies regarding semantic language processing to see whether processing icons is significantly different from processing other types of stimuli or not with collected neuroimaging data. In addition, it should be noted that the "no differences" findings in the fMRI contrasts did not necessarily mean that there were no differences in the states of participants' neural mechanisms at all. Such findings is based on statistical principles of choosing a threshold that was determined by a Z score of the BOLD signals to decide whether a cluster of the fMRI contrast was statistically significant to be considered as a modulated activation acrroding to the comparison of two experimental conditions. The threshold level ($Z>2.3$) used in this dissertation was a well-accepted standard in fMRI research.

Conclusion

In short, by generating words, English and Chinese speakers used the same language-based semantic systems with slightly different emphases in the IFG and the SMG that were responsible for phonological processing, syntactic processing, and complex information integration to interpret meanings of icons, pictures, single English words, and Chinese characters during the cognitive task of sorting stimuli into concrete and abstract categories, and icons were processed more like pictures and not as logographical words.

The participants were using language-based semantic processing, especially phonological and syntactic processing, when they were doing the concrete vs. abstract judgment regardless of the types of visual information (i.e. icons, pictures, single English words, and Chinese characters) that were presented. The seven areas of the language-based semantic system in the left hemisphere proposed by Binder et al. (2009), and corresponding symmetrical areas in the right hemisphere were significantly active while the participants were interpreting these four types of visual information with the concrete vs. abstract judgment task.

As to correctly interpreting icons, modulated activations of brain areas share great similarities in the condition of interpreting pictures using a smaller network that is more focused in the left hemisphere. On the other hand, in contrast to interpreting texts like single English words and Chinese characters, although interpreting icons required brain areas that were essential for language processing, the pattern of modulated activations of these areas was significantly different from the pattern of interpreting these two types of texts in the contrast analyses.

In conclusion, according to the fMRI data collected in Study Three, icons are not processed as logographical words when people are interpreting their meanings despite the fact that the language-based semantic system in the brain is used.

Chapter Seven: Conclusion

Summary of Important Findings and Implications

The author aimed to investigate how people behaviorally and cognitively process icons in the theoretical foundation of semiotics. Methods of survey statistics, behavioral experiment, and neuroimaging research were employed to explore the syntactic, pragmatic, and semantic aspects of icon interpretation in terms of how people perform concrete versus abstract judgment with icons, pictures, English words, and Chinese characters. The goal was to examine the hypothesis that icons are cognitively processed as logographical words by people with a series of three studies.

In Study One, according to the statistical analyses of normative ratings of icons, pictures, English words, and Chinese characters in terms of participants' concrete versus abstract interpretations, the proposition of icons being more than just pictures and being regarded as logographical words is incorrect. In addition, under the experimental conditions of the survey statistics, unaffected by the language of participants, pictures and icons are more ambiguous (i.e., have statistically significantly higher rating scores in both concrete and abstract categories) than English words and Chinese characters in terms of conveying the immediate semantics of objects and concepts. Findings of Study One imply that despite being carefully crafted, icons might still be fundamentally inferior to texts in communicating context to end-users.

In Study Two, it was found that participants did not read icons as words in terms of accuracy and efficiency in behavioral performance. Similar to interpreting pictures, reading icons was slower and was prone to more errors than reading single words. With repeated exposure and retention, participants could correctly interpret icons faster than pictures in later runs, but participants still performed the task the best with their native languages. Findings of Study Two also imply that without contextual aids, even well-selected icons are fundamentally inferior to single words to effectively and efficiently convey the immediate semantics of objects and concepts in terms of people's accuracy and efficiency in performance.

In Study Three, BOLD contrasts of neuroimaging data revealed that 1) there were modulated activations in the left IFG and the left SMG indicating that participants were generating words while doing the cognitive task of concrete vs. abstract judgment regardless of the types of visual information, 2) there were also modulated activations in the brain that were associated to the left-lateralized (but not restricted to such a lateralization) network of language-based semantic processing while participants were interpreting all four types of visual information, and 3) specific contrasts of modulated activations in our participants' brains suggested although the modulated activations might be more weighted in the left IFG of English speakers and in the left SMG of Chinese speakers for the task, how these two groups used the language-based semantic system in the brain was not significantly different from each other. Such modulated activations were also influenced by the types of visual information, indicating that the process of interpreting meanings of icons was less complicated than interpreting pictures, and significantly different from single English word or Chinese character processing.

Findings of this dissertation 1) suggest that, without the support of context such as localized texts, icons are less likely to provide effective and efficient communication in terms of universal interpretations; 2) provide empirical evidence to connect the semantic system of language processing in the brain to the cognitive mechanisms of icon interpretation, and 3) refute the claim that icons are cognitively processed as logographical words although they share the neural network that is essential for semantic interpretation in the brain.

Future Research

For future research, the author will focus on how different types of visual information are used to help solve problems and aid decision making with an emphasis on the use of icons in different contexts such as conditions and environments.

The short-term goal is to further extend this dissertation in depth by building a database of 1000 standardized icons for future research. These icons need to be examined by a larger population of representative users to determine their features, such as taxonomy, semantics, familiarity, learnability, and usability in both quantitative and qualitative measures. The author envisions using various behavioral surveys or online questionnaires to collect these measures based on assessments done by participants. A promising tool of statistical data collection that can reach a global population of representative users, for example, would be Amazon Mechanical Turk that is capable of crowdsourcing tasks.

The long-term goal will be to use these icons to study how people cognitively construct interpretations of meanings of visual information under various conditions such as different computing environments or social interactions. Studies might involve behavioral experiments and neuroimaging methods (e.g., eye-tracking, EEG, MEG or fMRI) to investigate cognitive processes of icon recognition on an individual or social level. The author believes that such research can help contribute to the fundamental knowledge that is required to develop brain-computer interfaces in the future.

Conclusion

People do not behaviorally or cognitivey process icons as words. Interpreting icons is slower, and yields more errors than interpreting single words. In contrast to reading texts, people might re-learn icons in every new task and require additional resources in the brain to interpret them. Despite the fact that well-designed icons are less ambiguous, more efficient, easier to interpret than pictures, and require the semantic system of language processing in the brain to be cognitively processed by people, icons are syntactically, pragmatically, semantically not logographical words according to the measures collected from participants in this dissertation.

Human icon processing and icon interpretation in fact occur in a wider and much more complex context. This dissertation has provided empirical evidence of statistical, behavioral, and neuroimaging measures of how human icon processing works. Findings of this dissertation have indicated that although icons are designed to communicate across language barriers, they are still not as effective and efficient as localized textual instructions and could be prone to ambiguity or interpretations that do not correspond to the intended origin. An infamous example is the parody interpretation of the hand dryer’s instructional signs: “Push Button, Receive Bacon (Figure 7.1)” that has been popularly distributed on the internet since 2004 as a joke indicating that once the original context is removed, symbols can mean anything. This particular instance actually became the research inspiration of this dissertation.

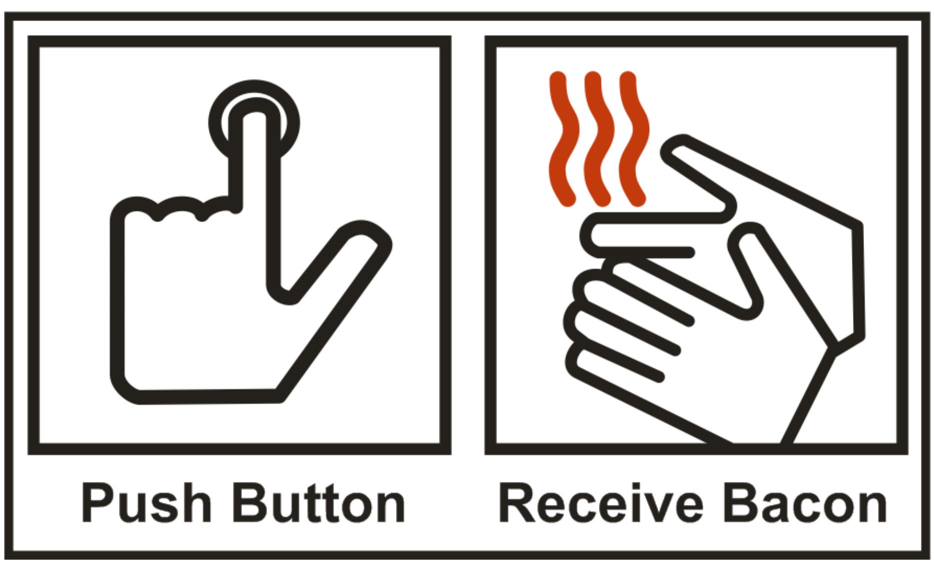


Figure 7.1 A Parody Example of Instructional Signs of the Hand Dryer

As Watzman and Re (2008) and Freeman (2000, 2002) suggested that meanings of symbols were sociocultural and cognitive products of end-users' mental activities, the author of this dissertation endeavored to create a window to see how such products were generated in aspects of semiotic dimensions in settings of empirical observations. Symbols like icons, pictures, and texts are major elements of visual information in information systems. Every day we spend a significant amount of time interacting with these three types of visual information on our cell phones, computers, and other electronic devices that have graphical user interfaces (GUIs). If we stumble upon ambiguous symbols on GUIs that cause us to slow down our tasks of finding things that we need, a two-second delay in every interaction for an average of a thousand times will cost us additional 33 minutes per day. Therefore, it is important to study how people read and interpret meanings of symbols, and this understanding of human information processing and human factors will allow us to design better interactive information and systems that will not waste users' time.

Findings of this dissertation demonstrated that there were fundamental differences in the graphical and textual representation of objects and concepts; people's behavioral performace with graphical and textual information, and utilization of brain resources to process graphical and textual information. The author believes that these findings provide profound insights to interface designers about the use of graphical symbols. For example, designers should always avoid using abstract symbols because they are harder for people to understand and they take people more time to respond to them. Designers should also beware of introducing novel symbols that have never been seen before because even with well-selected and highly-comprehensible icons, it would take people at least 100 times of interactions (25 trials in four runs) to reach their best user performance with a simple task provided that they would not be frustrated by early mistakes. In addition, a simple text instruction might be the best solution when the designer does not have the luxury of making rich visual cues and still wants to deliver an important message in a critical situation that requires people to respond quickly.

It is the author's sincere hope that findings of this dissertation will inform researchers in human factors and HCI designers for a better understanding of the role of graphical and textual of information in human activities that involve the use of information systems that manifest social media the use symbols and texts to interface communication with this knowledge—independently, icons are more ambiguous and are not as accurate and efficient as texts in terms of conveying specific meanings and people need additional context and brain resources to help them learn the meanings of symbols. The author sincerely suggests that designers of system interfaces and interactive information should consider such a factor revealed by the empirical evidence of this dissertation when they are implementing elements of graphical and textual cues in their design. The author believes that such awareness of designers can help produce better information systems that will not significantly delay users in their micro-interactions that can accumulate a lot of time that is unnecessarily wasted.

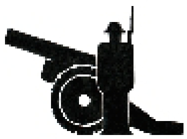
Appendices

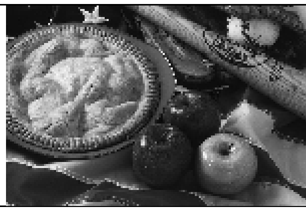
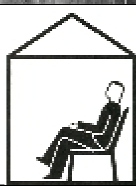
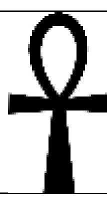
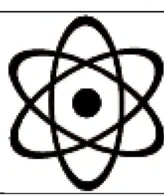
Appendix A: The Web-based Questionnaire Used in Study One

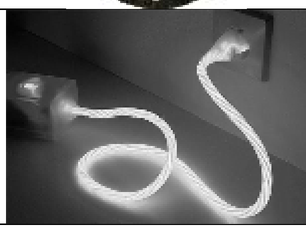
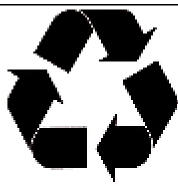
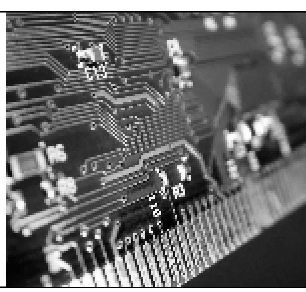
Survey: Concrete (Object) vs. Abstract (Concept) Visual Stimuli

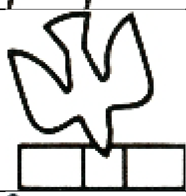
1. You are: (If you are a certain language user who cannot read Chinese, you can skip those questions about Chinese characters by answering N/A in the survey later.)
   a. An English native speaker who cannot read Chinese
   b. An English native speaker who can read Chinese as a second language
   c. A Chinese native speaker who can read English as a second language
   d. A Chinese-English biLingual
   e. Other (please specify: e.g., a certain language user who read English as a second language)
2. Your gender:
   a. Male
   b. Female
3. Your age:
   a. 18-25
   b. 26-35
   c. 36-45
   d. 46+
4. Your (current) highest education level:
   a. High school
   b. College
   c. Graduate school
5. Your e-mail address (optional, you shall provide it only if you are interested in our follow-up lab study):

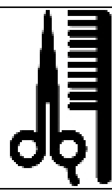
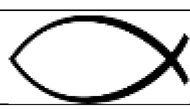
Please sort the following 500 visual stimuli (including icons, pictures, English words, and Chinese characters) into two major categories: concrete and abstract. You'll have 5 options for each stimulus: very concrete; concrete; abstract; very abstract; N/A (can't decide). **If you are a certain language user who cannot read Chinese, you can skip those questions about Chinese characters by answering N/A in the survey.** Generally, a concrete visual stimulus is a stimulus that represents or refers to a single object or substance that exists physically. An abstract visual stimulus is a stimulus that represents or refers to states, events, concepts, feelings, or qualities that have no physical existence. By your interpretation of the above definition, please choose the best option for each stimulus. Don't think too long about each answer; just respond with your first impression.

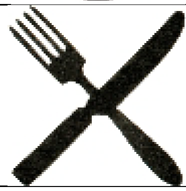
1		very concrete	concrete	Abstract	very abstract	N/A
2		very concrete	concrete	abstract	very abstract	N/A
3	water	very concrete	concrete	abstract	very abstract	N/A
4		very concrete	concrete	abstract	very abstract	N/A
5	能	very concrete	concrete	abstract	very abstract	N/A
6		very concrete	concrete	abstract	very abstract	N/A
7	space	very concrete	concrete	abstract	very abstract	N/A
8		very concrete	concrete	abstract	very abstract	N/A
9	木	very concrete	concrete	abstract	very abstract	N/A
10		very concrete	concrete	abstract	very abstract	N/A
11	春	very concrete	concrete	abstract	very abstract	N/A

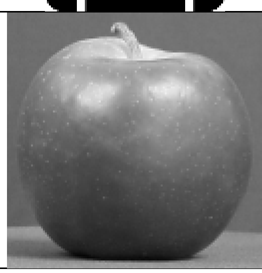
12		very concrete	concrete	abstract	very abstract	N/A
13	law	very concrete	concrete	abstract	very abstract	N/A
14	陰	very concrete	concrete	abstract	very abstract	N/A
15	上	very concrete	concrete	abstract	very abstract	N/A
16		very concrete	concrete	abstract	very abstract	N/A
17		very concrete	concrete	abstract	very abstract	N/A
18	danger	very concrete	concrete	abstract	very abstract	N/A
19	船	very concrete	concrete	abstract	very abstract	N/A
20	東	very concrete	concrete	abstract	very abstract	N/A
21		very concrete	concrete	abstract	very abstract	N/A
22	variety	very concrete	concrete	abstract	very abstract	N/A
23		very concrete	concrete	abstract	very abstract	N/A

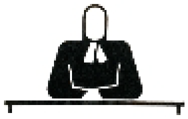
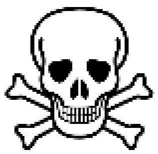
24		very concrete	concrete	abstract	very abstract	N/A
25		very concrete	concrete	abstract	very abstract	N/A
26		very concrete	concrete	abstract	very abstract	N/A
27	德	very concrete	concrete	abstract	very abstract	N/A
28		very concrete	concrete	abstract	very abstract	N/A
29		very concrete	concrete	abstract	very abstract	N/A
30	松	very concrete	concrete	abstract	very abstract	N/A
31	idea	very concrete	concrete	abstract	very abstract	N/A
32		very concrete	concrete	abstract	very abstract	N/A
33	哭	very concrete	concrete	abstract	very abstract	N/A

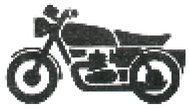
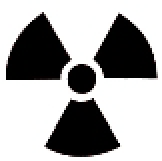
34	床	very concrete	concrete	abstract	very abstract	N/A
35		very concrete	concrete	abstract	very abstract	N/A
36		very concrete	concrete	abstract	very abstract	N/A
37		very concrete	concrete	abstract	very abstract	N/A
38		very concrete	concrete	abstract	very abstract	N/A
39	命	very concrete	concrete	abstract	very abstract	N/A
40		very concrete	concrete	abstract	very abstract	N/A
41		very concrete	concrete	abstract	very abstract	N/A
42	犬	very concrete	concrete	abstract	very abstract	N/A
43	年	very concrete	concrete	abstract	very abstract	N/A

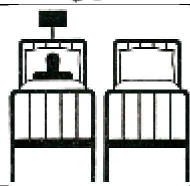
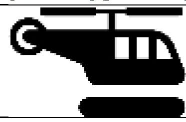
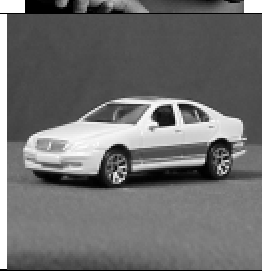
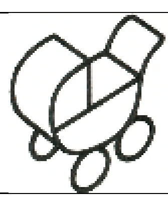
44		very concrete	concrete	abstract	very abstract	N/A
45	house	very concrete	concrete	abstract	very abstract	N/A
46		very concrete	concrete	abstract	very abstract	N/A
47		very concrete	concrete	abstract	very abstract	N/A
48	目	very concrete	concrete	abstract	very abstract	N/A
49		very concrete	concrete	abstract	very abstract	N/A
50	land	very concrete	concrete	abstract	very abstract	N/A
51	飯	very concrete	concrete	abstract	very abstract	N/A
52	mind	very concrete	concrete	abstract	very abstract	N/A
53	heat	very concrete	concrete	abstract	very abstract	N/A
54		very concrete	concrete	abstract	very abstract	N/A
55	海	very concrete	concrete	abstract	very abstract	N/A

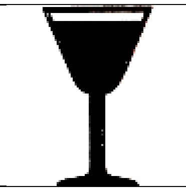
56		very concrete	concrete	abstract	very abstract	N/A
57		very concrete	concrete	abstract	very abstract	N/A
58	head	very concrete	concrete	abstract	very abstract	N/A
59		very concrete	concrete	abstract	very abstract	N/A
60		very concrete	concrete	abstract	very abstract	N/A
61		very concrete	concrete	abstract	very abstract	N/A
62	林	very concrete	concrete	abstract	very abstract	N/A
63		very concrete	concrete	abstract	very abstract	N/A
64	size	very concrete	concrete	abstract	very abstract	N/A

65		very concrete	concrete	abstract	very abstract	N/A
66		very concrete	concrete	abstract	very abstract	N/A
67	金	very concrete	concrete	abstract	very abstract	N/A
68		very concrete	concrete	abstract	very abstract	N/A
69		very concrete	concrete	abstract	very abstract	N/A
70	bus	very concrete	concrete	abstract	very abstract	N/A
71	earth	very concrete	concrete	abstract	very abstract	N/A
72	purpose	very concrete	concrete	abstract	very abstract	N/A
73		very concrete	concrete	abstract	very abstract	N/A
74	hand	very concrete	concrete	abstract	very abstract	N/A
75		very concrete	concrete	abstract	very abstract	N/A

76		very concrete	concrete	abstract	very abstract	N/A
77	雨	very concrete	concrete	abstract	very abstract	N/A
78	picture	very concrete	concrete	abstract	very abstract	N/A
79		very concrete	concrete	abstract	very abstract	N/A
80	紙	very concrete	concrete	abstract	very abstract	N/A
81	悲	very concrete	concrete	abstract	very abstract	N/A
82		very concrete	concrete	abstract	very abstract	N/A
83		very concrete	concrete	abstract	very abstract	N/A
84		very concrete	concrete	abstract	very abstract	N/A
85		very concrete	concrete	abstract	very abstract	N/A
86	正	very concrete	concrete	abstract	very abstract	N/A

87		very concrete	concrete	abstract	very abstract	N/A
88		very concrete	concrete	abstract	very abstract	N/A
89	雎	very concrete	concrete	abstract	very abstract	N/A
90	paper	very concrete	concrete	abstract	very abstract	N/A
91	sun	very concrete	concrete	abstract	very abstract	N/A
92	窗	very concrete	concrete	abstract	very abstract	N/A
93	強	very concrete	concrete	abstract	very abstract	N/A
94		very concrete	concrete	abstract	very abstract	N/A
95	光	very concrete	concrete	abstract	very abstract	N/A
96		very concrete	concrete	abstract	very abstract	N/A
97	義	very concrete	concrete	abstract	very abstract	N/A
98		very concrete	concrete	abstract	very abstract	N/A
99	room	very concrete	concrete	abstract	very abstract	N/A

100		very concrete	concrete	abstract	very abstract	N/A
101		very concrete	concrete	abstract	very abstract	N/A
102		very concrete	concrete	abstract	very abstract	N/A
103	惡	very concrete	concrete	abstract	very abstract	N/A
104	下	very concrete	concrete	abstract	very abstract	N/A
105	progress	very concrete	concrete	abstract	very abstract	N/A
106		very concrete	concrete	abstract	very abstract	N/A
107		very concrete	concrete	abstract	very abstract	N/A
108	sea	very concrete	concrete	abstract	very abstract	N/A
109		very concrete	concrete	abstract	very abstract	N/A
110	陽	very concrete	concrete	abstract	very abstract	N/A

111		very concrete	concrete	abstract	very abstract	N/A
112	experience	very concrete	concrete	abstract	very abstract	N/A
113		very concrete	concrete	abstract	very abstract	N/A
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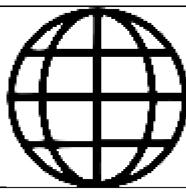
115		very concrete	concrete	abstract	very abstract	N/A
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117	果	very concrete	concrete	abstract	very abstract	N/A
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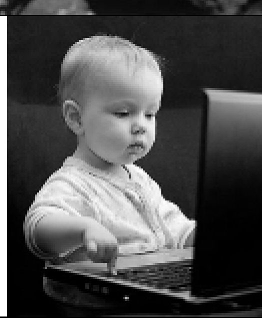
119		very concrete	concrete	abstract	very abstract	N/A
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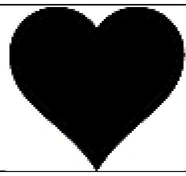
121	car	very concrete	concrete	abstract	very abstract	N/A

122		very concrete	concrete	abstract	very abstract	N/A
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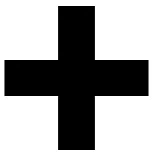
124		very concrete	concrete	abstract	very abstract	N/A
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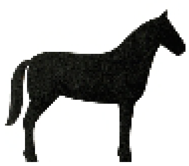
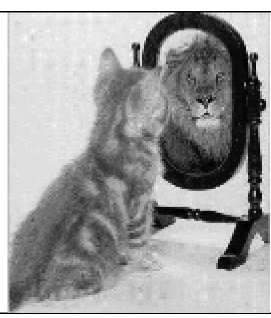
126		very concrete	concrete	abstract	very abstract	N/A
127	face	very concrete	concrete	abstract	very abstract	N/A
128	皮	very concrete	concrete	abstract	very abstract	N/A
129	average	very concrete	concrete	abstract	very abstract	N/A
130	雪	very concrete	concrete	abstract	very abstract	N/A
131		very concrete	concrete	abstract	very abstract	N/A
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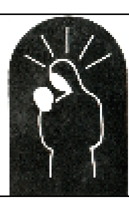
133		very concrete	concrete	abstract	very abstract	N/A

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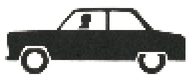
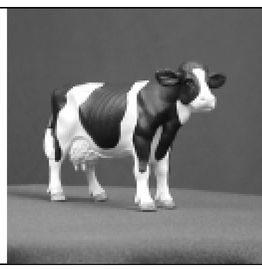
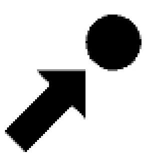
135		very concrete	concrete	abstract	very abstract	N/A
136	葉	very concrete	concrete	abstract	very abstract	N/A
137		very concrete	concrete	abstract	very abstract	N/A
138	筆	very concrete	concrete	abstract	very abstract	N/A
139		very concrete	concrete	abstract	very abstract	N/A
140	door	very concrete	concrete	abstract	very abstract	N/A
141		very concrete	concrete	abstract	very abstract	N/A
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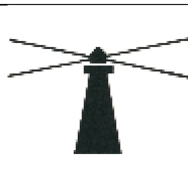
143		very concrete	concrete	abstract	very abstract	N/A
144	fish	very concrete	concrete	abstract	very abstract	N/A

145		very concrete	concrete	abstract	very abstract	N/A
146	真	very concrete	concrete	abstract	very abstract	N/A
147	concern	very concrete	concrete	abstract	very abstract	N/A
148	music	very concrete	concrete	abstract	very abstract	N/A
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150		very concrete	concrete	abstract	very abstract	N/A
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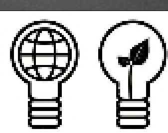
152		very concrete	concrete	abstract	very abstract	N/A
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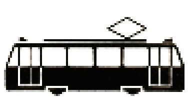
154		very concrete	concrete	abstract	very abstract	N/A
155		very concrete	concrete	abstract	very abstract	N/A

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157	ring	very concrete	concrete	abstract	very abstract	N/A
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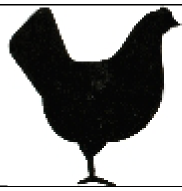
159		very concrete	concrete	abstract	very abstract	N/A
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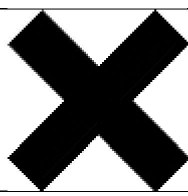
161		very concrete	concrete	abstract	very abstract	N/A
162		very concrete	concrete	abstract	very abstract	N/A
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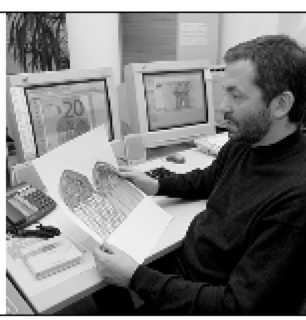
164	肉	very concrete	concrete	abstract	very abstract	N/A
165	高	very concrete	concrete	abstract	very abstract	N/A
166		very concrete	concrete	abstract	very abstract	N/A

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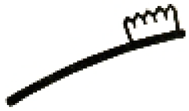
168		very concrete	concrete	abstract	very abstract	N/A
169	屋	very concrete	concrete	abstract	very abstract	N/A
170	心	very concrete	concrete	abstract	very abstract	N/A
171		very concrete	concrete	abstract	very abstract	N/A
172	米	very concrete	concrete	abstract	very abstract	N/A
173	measure	very concrete	concrete	abstract	very abstract	N/A
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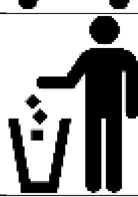
175		very concrete	concrete	abstract	very abstract	N/A
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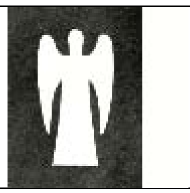
177		very concrete	concrete	abstract	very abstract	N/A

178		very concrete	concrete	abstract	very abstract	N/A
179	quality	very concrete	concrete	abstract	very abstract	N/A
180	衣	very concrete	concrete	abstract	very abstract	N/A
181	天	very concrete	concrete	abstract	very abstract	N/A
182		very concrete	concrete	abstract	very abstract	N/A
183	力	very concrete	concrete	abstract	very abstract	N/A
184	book	very concrete	concrete	abstract	very abstract	N/A
185	energy	very concrete	concrete	abstract	very abstract	N/A
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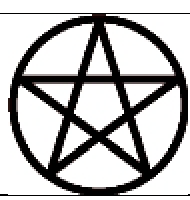
187	書	very concrete	concrete	abstract	very abstract	N/A
188		very concrete	concrete	abstract	very abstract	N/A
189	利	very concrete	concrete	abstract	very abstract	N/A

190		very concrete	concrete	abstract	very abstract	N/A
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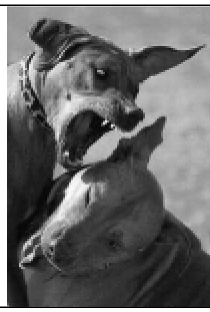
193		very concrete	concrete	abstract	very abstract	N/A
194	手	very concrete	concrete	abstract	very abstract	N/A
195		very concrete	concrete	abstract	very abstract	N/A
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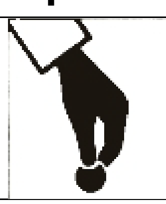
197	square	very concrete	concrete	abstract	very abstract	N/A
198		very concrete	concrete	abstract	very abstract	N/A

199	courage	very concrete	concrete	abstract	very abstract	N/A
200	形	very concrete	concrete	abstract	very abstract	N/A
201	snow	very concrete	concrete	abstract	very abstract	N/A
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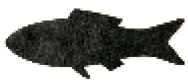
203		very concrete	concrete	abstract	very abstract	N/A
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205	rain	very concrete	concrete	abstract	very abstract	N/A
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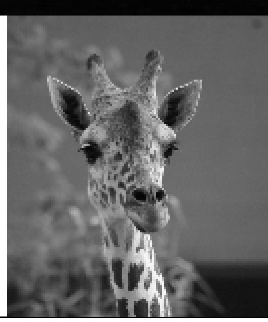
207		very concrete	concrete	abstract	very abstract	N/A
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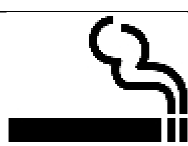
209		very concrete	concrete	abstract	very abstract	N/A

210	花	very concrete	concrete	abstract	very abstract	N/A
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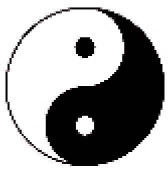
212	腦	very concrete	concrete	abstract	very abstract	N/A
213		very concrete	concrete	abstract	very abstract	N/A
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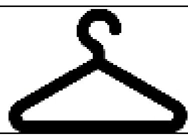
215	sky	very concrete	concrete	abstract	very abstract	N/A
216		very concrete	concrete	abstract	very abstract	N/A
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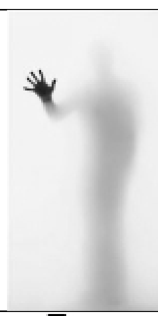
218		very concrete	concrete	abstract	very abstract	N/A
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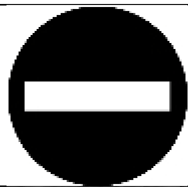
220	work	very concrete	concrete	abstract	very abstract	N/A

221		very concrete	concrete	abstract	very abstract	N/A
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223	fire	very concrete	concrete	abstract	very abstract	N/A
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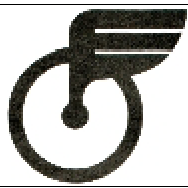
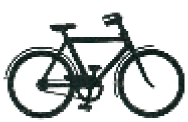
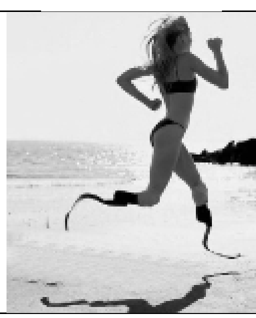
227		very concrete	concrete	abstract	very abstract	N/A
228		very concrete	concrete	abstract	very abstract	N/A
229		very concrete	concrete	abstract	very abstract	N/A
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232	reason	very concrete	concrete	abstract	very abstract	N/A
233		very concrete	concrete	abstract	very abstract	N/A
234		very concrete	concrete	abstract	very abstract	N/A
235	wind	very concrete	concrete	abstract	very abstract	N/A
236		very concrete	concrete	abstract	very abstract	N/A
237	氣	very concrete	concrete	abstract	very abstract	N/A
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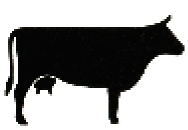
240	tree	very concrete	concrete	abstract	very abstract	N/A
241		very concrete	concrete	abstract	very abstract	N/A
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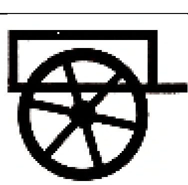
243	山	very concrete	concrete	abstract	very abstract	N/A
244		very concrete	concrete	abstract	very abstract	N/A

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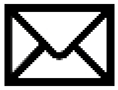
247		very concrete	concrete	abstract	very abstract	N/A
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249	善	very concrete	concrete	abstract	very abstract	N/A
250	無	very concrete	concrete	abstract	very abstract	N/A
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252	table	very concrete	concrete	abstract	very abstract	N/A
253		very concrete	concrete	abstract	very abstract	N/A
254		very concrete	concrete	abstract	very abstract	N/A
255	bed	very concrete	concrete	abstract	very abstract	N/A
256	草	very concrete	concrete	abstract	very abstract	N/A

257		very concrete	concrete	abstract	very abstract	N/A
258	福	very concrete	concrete	abstract	very abstract	N/A
259		very concrete	concrete	abstract	very abstract	N/A
260	death	very concrete	concrete	abstract	very abstract	N/A
261	time	very concrete	concrete	abstract	very abstract	N/A
262		very concrete	concrete	abstract	very abstract	N/A
263	性	very concrete	concrete	abstract	very abstract	N/A
264	process	very concrete	concrete	abstract	very abstract	N/A
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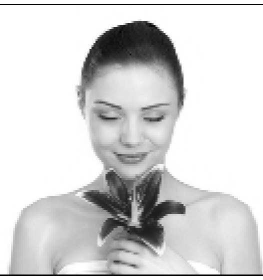
268		very concrete	concrete	abstract	very abstract	N/A

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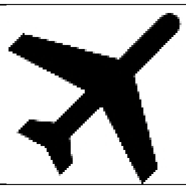
273		very concrete	concrete	abstract	very abstract	N/A
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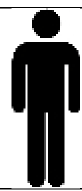
275		very concrete	concrete	abstract	very abstract	N/A
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278	gun	very concrete	concrete	abstract	very abstract	N/A
279	布	very concrete	concrete	abstract	very abstract	N/A
280	影	very concrete	concrete	abstract	very abstract	N/A

281	身	very concrete	concrete	abstract	very abstract	N/A
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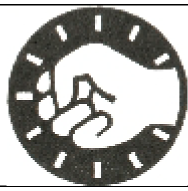
285		very concrete	concrete	abstract	very abstract	N/A
286	cause	very concrete	concrete	abstract	very abstract	N/A
287	hair	very concrete	concrete	abstract	very abstract	N/A
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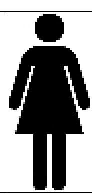
291		very concrete	concrete	abstract	very abstract	N/A
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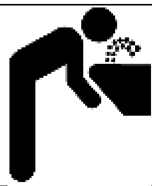
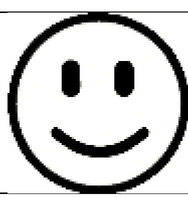
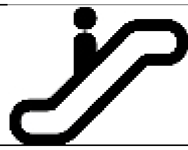
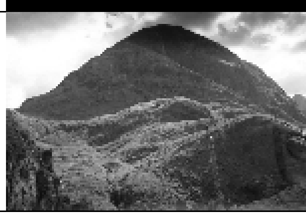
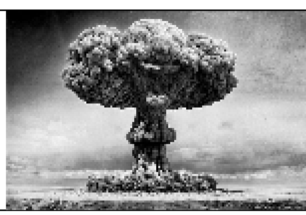
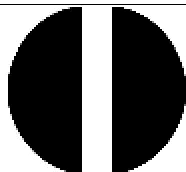
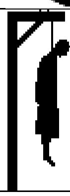
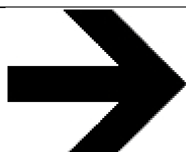
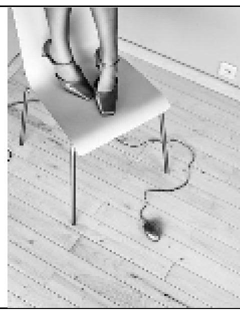
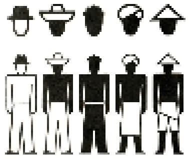
295		very concrete	concrete	abstract	very abstract	N/A
296	今	very concrete	concrete	abstract	very abstract	N/A
297		very concrete	concrete	abstract	very abstract	N/A
298		very concrete	concrete	abstract	very abstract	N/A
299	兒	very concrete	concrete	abstract	very abstract	N/A
300	chief	very concrete	concrete	abstract	very abstract	N/A
301		very concrete	concrete	abstract	very abstract	N/A
302	bird	very concrete	concrete	abstract	very abstract	N/A
303		very concrete	concrete	abstract	very abstract	N/A
304	火	very concrete	concrete	abstract	very abstract	N/A

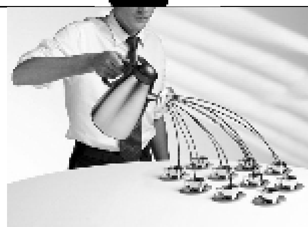
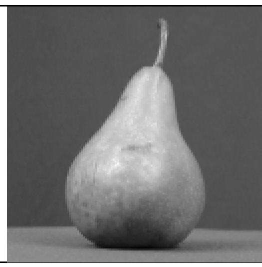
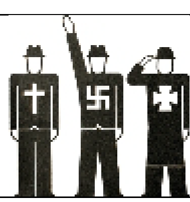
305		very concrete	concrete	abstract	very abstract	N/A
306	wood	very concrete	concrete	abstract	very abstract	N/A
307		very concrete	concrete	abstract	very abstract	N/A
308		very concrete	concrete	abstract	very abstract	N/A
309	end	very concrete	concrete	abstract	very abstract	N/A
310	help	very concrete	concrete	abstract	very abstract	N/A
311		very concrete	concrete	abstract	very abstract	N/A
312		very concrete	concrete	abstract	very abstract	N/A
313	日	very concrete	concrete	abstract	very abstract	N/A
314		very concrete	concrete	abstract	very abstract	N/A
315	孝	very concrete	concrete	abstract	very abstract	N/A

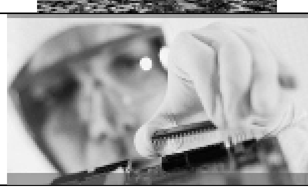
316		very concrete	concrete	abstract	very abstract	N/A
317		very concrete	concrete	abstract	very abstract	N/A
318	wish	very concrete	concrete	abstract	very abstract	N/A
319	fly	very concrete	concrete	abstract	very abstract	N/A
320		very concrete	concrete	abstract	very abstract	N/A
321		very concrete	concrete	abstract	very abstract	N/A
322	thought	very concrete	concrete	abstract	very abstract	N/A
323		very concrete	concrete	abstract	very abstract	N/A
324	石	very concrete	concrete	abstract	very abstract	N/A
325		very concrete	concrete	abstract	very abstract	N/A

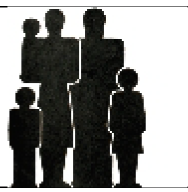
326		very concrete	concrete	abstract	very abstract	N/A
327	hope	very concrete	concrete	abstract	very abstract	N/A
328		very concrete	concrete	abstract	very abstract	N/A
329		very concrete	concrete	abstract	very abstract	N/A
330	church	very concrete	concrete	abstract	very abstract	N/A
331	酒	very concrete	concrete	abstract	very abstract	N/A
332		very concrete	concrete	abstract	very abstract	N/A
333		very concrete	concrete	abstract	very abstract	N/A
334		very concrete	concrete	abstract	very abstract	N/A
335	象	very concrete	concrete	abstract	very abstract	N/A
336	doctor	very concrete	concrete	abstract	very abstract	N/A

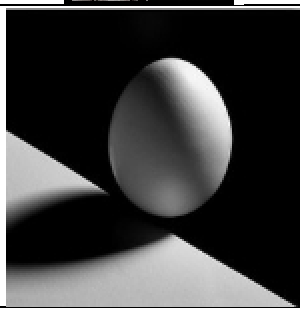
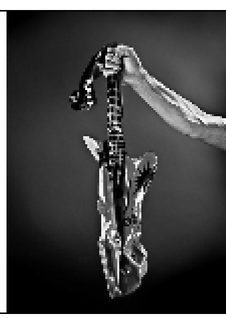
337	style	very concrete	concrete	abstract	very abstract	N/A
338	竹	very concrete	concrete	abstract	very abstract	N/A
339		very concrete	concrete	abstract	very abstract	N/A
340	education	very concrete	concrete	abstract	very abstract	N/A
341		very concrete	concrete	abstract	very abstract	N/A
342	愛	very concrete	concrete	abstract	very abstract	N/A
343		very concrete	concrete	abstract	very abstract	N/A
344	farm	very concrete	concrete	abstract	very abstract	N/A
345	meat	very concrete	concrete	abstract	very abstract	N/A
346		very concrete	concrete	abstract	very abstract	N/A

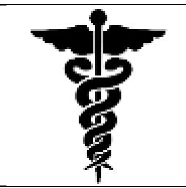
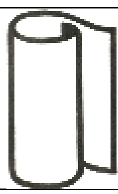
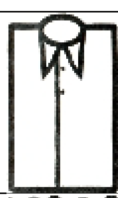
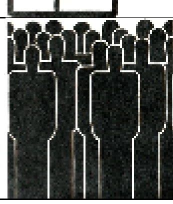
347	車	very concrete	concrete	abstract	very abstract	N/A
348		very concrete	concrete	abstract	very abstract	N/A
349	夢	very concrete	concrete	abstract	very abstract	N/A
350		very concrete	concrete	abstract	very abstract	N/A
351	月	very concrete	concrete	abstract	very abstract	N/A
352		very concrete	concrete	abstract	very abstract	N/A
353	hill	very concrete	concrete	abstract	very abstract	N/A
354		very concrete	concrete	abstract	very abstract	N/A
355	attention	very concrete	concrete	abstract	very abstract	N/A
356	television	very concrete	concrete	abstract	very abstract	N/A
357	number	very concrete	concrete	abstract	very abstract	N/A

358		very concrete	concrete	abstract	very abstract	N/A
359		very concrete	concrete	abstract	very abstract	N/A
360	corn	very concrete	concrete	abstract	very abstract	N/A
361		very concrete	concrete	abstract	very abstract	N/A
362	人	very concrete	concrete	abstract	very abstract	N/A
363		very concrete	concrete	abstract	very abstract	N/A
364	♂	very concrete	concrete	abstract	very abstract	N/A
365	value	very concrete	concrete	abstract	very abstract	N/A
366	時	very concrete	concrete	abstract	very abstract	N/A
367		very concrete	concrete	abstract	very abstract	N/A

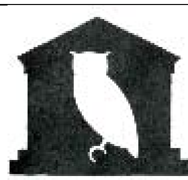
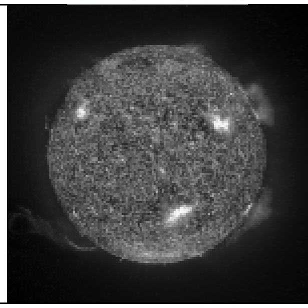
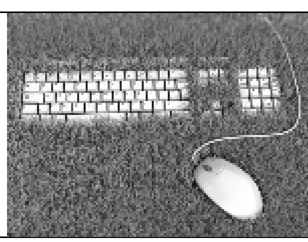
368		very concrete	concrete	abstract	very abstract	N/A
369	peace	very concrete	concrete	abstract	very abstract	N/A
370	wheel	very concrete	concrete	abstract	very abstract	N/A
371		very concrete	concrete	abstract	very abstract	N/A
372	畫	very concrete	concrete	abstract	very abstract	N/A
373		very concrete	concrete	abstract	very abstract	N/A
374		very concrete	concrete	abstract	very abstract	N/A
375	life	very concrete	concrete	abstract	very abstract	N/A
376	地	very concrete	concrete	abstract	very abstract	N/A
377		very concrete	concrete	abstract	very abstract	N/A

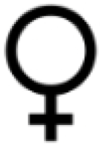
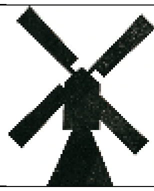
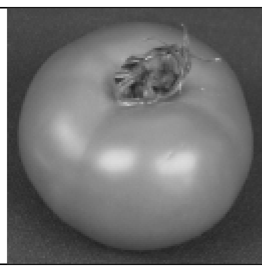
378		very concrete	concrete	abstract	very abstract	N/A
379	電	very concrete	concrete	abstract	very abstract	N/A
380		very concrete	concrete	abstract	very abstract	N/A
381		very concrete	concrete	abstract	very abstract	N/A
382	train	very concrete	concrete	abstract	very abstract	N/A
383		very concrete	concrete	abstract	very abstract	N/A
384		very concrete	concrete	abstract	very abstract	N/A
385	light	very concrete	concrete	abstract	very abstract	N/A
386	仁	very concrete	concrete	abstract	very abstract	N/A
387		very concrete	concrete	abstract	very abstract	N/A

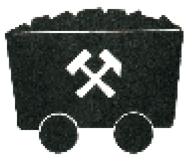
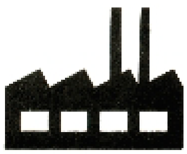
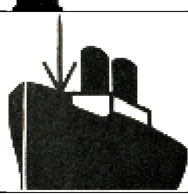
388	cattle	very concrete	concrete	abstract	very abstract	N/A
389		very concrete	concrete	abstract	very abstract	N/A
390		very concrete	concrete	abstract	very abstract	N/A
391	island	very concrete	concrete	abstract	very abstract	N/A
392		very concrete	concrete	abstract	very abstract	N/A
393	田	very concrete	concrete	abstract	very abstract	N/A
394	情	very concrete	concrete	abstract	very abstract	N/A
395		very concrete	concrete	abstract	very abstract	N/A
396	戸	very concrete	concrete	abstract	very abstract	N/A
397		very concrete	concrete	abstract	very abstract	N/A
398	子	very concrete	concrete	abstract	very abstract	N/A

399		very concrete	concrete	abstract	very abstract	N/A
400	stone	very concrete	concrete	abstract	very abstract	N/A
401		very concrete	concrete	abstract	very abstract	N/A
402		very concrete	concrete	abstract	very abstract	N/A
403	north	very concrete	concrete	abstract	very abstract	N/A
404		very concrete	concrete	abstract	very abstract	N/A
405	信	very concrete	concrete	abstract	very abstract	N/A
406	沙	very concrete	concrete	abstract	very abstract	N/A
407	笑	very concrete	concrete	abstract	very abstract	N/A
408		very concrete	concrete	abstract	very abstract	N/A
409		very concrete	concrete	abstract	very abstract	N/A

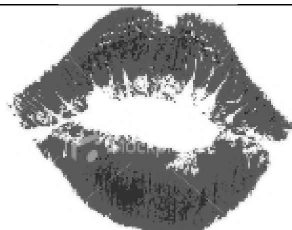
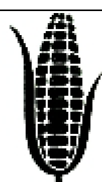
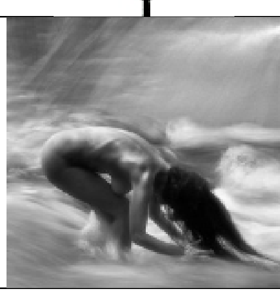
410	method	very concrete	concrete	abstract	very abstract	N/A
411	sense	very concrete	concrete	abstract	very abstract	N/A
412		very concrete	concrete	abstract	very abstract	N/A
413	power	very concrete	concrete	abstract	very abstract	N/A
414		very concrete	concrete	abstract	very abstract	N/A
415	secret	very concrete	concrete	abstract	very abstract	N/A
416	智	very concrete	concrete	abstract	very abstract	N/A
417		very concrete	concrete	abstract	very abstract	N/A
418		very concrete	concrete	abstract	very abstract	N/A
419		very concrete	concrete	abstract	very abstract	N/A
420	門	very concrete	concrete	abstract	very abstract	N/A
421	garden	very concrete	concrete	abstract	very abstract	N/A

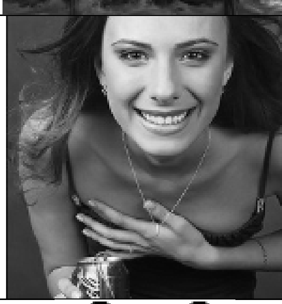
422		very concrete	concrete	abstract	very abstract	N/A
423		very concrete	concrete	abstract	very abstract	N/A
424		very concrete	concrete	abstract	very abstract	N/A
425	音	very concrete	concrete	abstract	very abstract	N/A
426		very concrete	concrete	abstract	very abstract	N/A
427	中	very concrete	concrete	abstract	very abstract	N/A
428	骨	very concrete	concrete	abstract	very abstract	N/A
429		very concrete	concrete	abstract	very abstract	N/A
430	chance	very concrete	concrete	abstract	very abstract	N/A

431		very concrete	concrete	abstract	very abstract	N/A
432		very concrete	concrete	abstract	very abstract	N/A
433		very concrete	concrete	abstract	very abstract	N/A
434	量	very concrete	concrete	abstract	very abstract	N/A
435		very concrete	concrete	abstract	very abstract	N/A
436	cat	very concrete	concrete	abstract	very abstract	N/A
437	麗	very concrete	concrete	abstract	very abstract	N/A
438	因	very concrete	concrete	abstract	very abstract	N/A
439		very concrete	concrete	abstract	very abstract	N/A
440	service	very concrete	concrete	abstract	very abstract	N/A
441	志	very concrete	concrete	abstract	very abstract	N/A

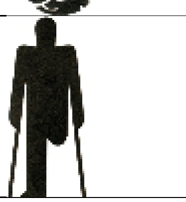
442		very concrete	concrete	abstract	very abstract	N/A
443		very concrete	concrete	abstract	very abstract	N/A
444	術	very concrete	concrete	abstract	very abstract	N/A
445		very concrete	concrete	abstract	very abstract	N/A
446		very concrete	concrete	abstract	very abstract	N/A
447		very concrete	concrete	abstract	very abstract	N/A
448	變	very concrete	concrete	abstract	very abstract	N/A
449		very concrete	concrete	abstract	very abstract	N/A
450	blood	very concrete	concrete	abstract	very abstract	N/A

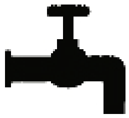
451		very concrete	concrete	abstract	very abstract	N/A
452	map	very concrete	concrete	abstract	very abstract	N/A
453		very concrete	concrete	abstract	very abstract	N/A
454		very concrete	concrete	abstract	very abstract	N/A
455	story	very concrete	concrete	abstract	very abstract	N/A
456		very concrete	concrete	abstract	very abstract	N/A
457		very concrete	concrete	abstract	very abstract	N/A
458	死	very concrete	concrete	abstract	very abstract	N/A

459		very concrete	concrete	abstract	very abstract	N/A
460	**mistake**	very concrete	concrete	abstract	very abstract	N/A
461		very concrete	concrete	abstract	very abstract	N/A
462		very concrete	concrete	abstract	very abstract	N/A
463		very concrete	concrete	abstract	very abstract	N/A
464	**rock**	very concrete	concrete	abstract	very abstract	N/A
465		very concrete	concrete	abstract	very abstract	N/A
466		very concrete	concrete	abstract	very abstract	N/A
467	**science**	very concrete	concrete	abstract	very abstract	N/A

468	足	very concrete	concrete	abstract	very abstract	N/A
469		very concrete	concrete	abstract	very abstract	N/A
470	past	very concrete	concrete	abstract	very abstract	N/A
471	血	very concrete	concrete	abstract	very abstract	N/A
472		very concrete	concrete	abstract	very abstract	N/A
473		very concrete	concrete	abstract	very abstract	N/A
474		very concrete	concrete	abstract	very abstract	N/A
475		very concrete	concrete	abstract	very abstract	N/A
476	glass	very concrete	concrete	abstract	very abstract	N/A

477		very concrete	concrete	abstract	very abstract	N/A
478		very concrete	concrete	abstract	very abstract	N/A
479		very concrete	concrete	abstract	very abstract	N/A
480	design	very concrete	concrete	abstract	very abstract	N/A
481	耳	very concrete	concrete	abstract	very abstract	N/A
482		very concrete	concrete	abstract	very abstract	N/A
483		very concrete	concrete	abstract	very abstract	N/A
484	practice	very concrete	concrete	abstract	very abstract	N/A

485		very concrete	concrete	abstract	very abstract	N/A
486	毛	very concrete	concrete	abstract	very abstract	N/A
487	gold	very concrete	concrete	abstract	very abstract	N/A
488		very concrete	concrete	abstract	very abstract	N/A
489		very concrete	concrete	abstract	very abstract	N/A
490	result	very concrete	concrete	abstract	very abstract	N/A
491		very concrete	concrete	abstract	very abstract	N/A
492		very concrete	concrete	abstract	very abstract	N/A
493	foot	very concrete	concrete	abstract	very abstract	N/A
494	數	very concrete	concrete	abstract	very abstract	N/A

495		very concrete	concrete	abstract	very abstract	N/A
496		very concrete	concrete	abstract	very abstract	N/A
497	support	very concrete	concrete	abstract	very abstract	N/A
498		very concrete	concrete	abstract	very abstract	N/A
499	臉	very concrete	concrete	abstract	very abstract	N/A
500	temperature	very concrete	concrete	abstract	very abstract	N/A

You have finished the questionnaire!

We sincerely thank you for all your efforts to complete this survey. Your participation will contribute to a better understanding of how people read different types of visual symbols.

If you have any question about the progress of this study, you can contact:

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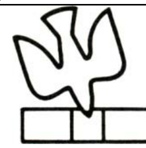
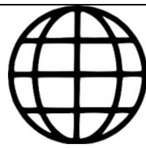
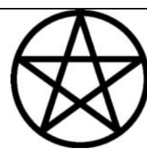
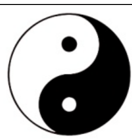
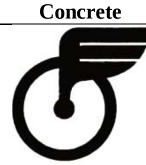
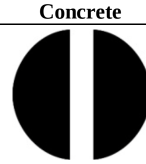
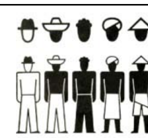
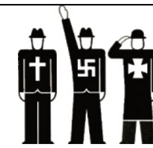
512-299-7671
huangsc@mail.utexas.edu

Again, thank you very much!

Appendix B: List of Selected 200 Stimuli Used in Study Two and Three

25 concrete and 25 abstract icons
(N=135, Mean= 2.30, Std. Deviation= .42, z < -1.00; z > 1.04)

 **Mean= 1.69; Z= -1.46** **Concrete**	 **Mean= 1.77; Z= -1.27** **Concrete**	 **Mean= 3.06; Z= 1.83** **Abstract**	 **Mean= 3.00; Z= 1.69** **Abstract**	 **Mean= 1.86; Z= -1.05** **Concrete**
 **Mean= 2.73; Z= 1.04** **Abstract**	 **Mean= 1.73; Z= -1.37** **Concrete**	 **Mean= 2.76; Z= 1.11** **Abstract**	 **Mean= 2.75; Z= 1.09** **Abstract**	 **Mean= 3.15; Z= 2.05** **Abstract**
 **Mean= 1.64; Z= -1.58** **Concrete**	 **Mean= 2.79; Z= 1.18** **Abstract**	 **Mean= 1.69; Z= -1.46** **Concrete**	 **Mean= 2.79; Z= 1.18** **Abstract**	 **Mean= 1.82; Z= -1.15** **Concrete**
 **Mean= 3.15; Z= 2.05** **Abstract**	 **Mean= 2.86; Z= 1.35** **Abstract**	 **Mean= 3.02; Z= 1.74** **Abstract**	 **Mean= 1.79; Z= -1.22** **Concrete**	 **Mean= 2.75; Z= 1.09** **Abstract**
 **Mean= 1.72; Z= -1.39** **Concrete**	 **Mean= 2.97; Z= 1.61** **Abstract**	 **Mean= 3.04; Z= 1.78** **Abstract**	 **Mean= 1.75; Z= -1.32** **Concrete**	 **Mean= 1.86; Z= -1.05** **Concrete**
 **Mean= 2.76; Z= 1.11** **Abstract**	 **Mean= 1.74; Z= -1.34** **Concrete**	 **Mean= 1.88; Z= -1.00** **Concrete**	 **Mean= 3.17; Z= 2.10** **Abstract**	 **Mean= 1.69; Z= -1.46** **Concrete**
 **Mean= 1.85; Z= -1.08** **Concrete**	 **Mean= 1.70; Z= -1.44** **Concrete**	 **Mean= 2.89; Z= 1.42** **Abstract**	 **Mean= 1.80; Z= -1.20** **Concrete**	 **Mean= 1.84; Z= -1.10** **Concrete**
 **Mean= 3.09; Z= 1.90** **Abstract**	 **Mean= 1.73; Z= -1.37** **Concrete**	 **Mean= 1.85; Z= -1.08** **Concrete**	 **Mean= 3.20; Z= 2.17** **Abstract**	 **Mean= 3.00; Z= 1.69** **Abstract**

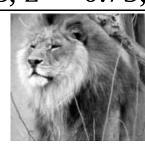
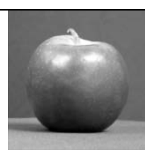
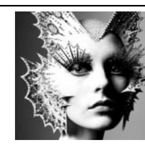
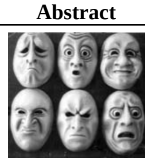
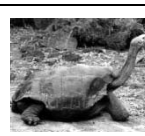
 Mean= 1.87; Z= -1.03 **Concrete**	 Mean= 3.11; Z= 1.95 **Abstract**	 Mean= 1.75; Z= -1.32 **Concrete**	 Mean= 3.05; Z= 1.81 **Abstract**	 Mean= 2.89; Z= 1.42 **Abstract**
 Mean= 1.80; Z= -1.20 **Concrete**	 Mean= 1.79; Z= -1.22 **Concrete**	 Mean= 3.06; Z= 1.83 **Abstract**	 Mean= 1.79; Z= -1.22 **Concrete**	 Mean= 2.84; Z= 1.30 **Abstract**

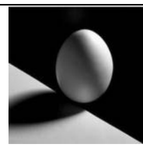
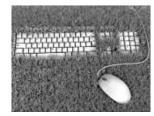
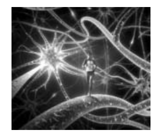
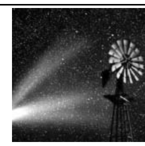
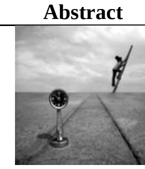
25 concrete and 25 abstract words
(N= 125, Mean= 2.11, Std. Deviation= .40, z < -1.03; z > 1.05)

water **Mean= 1.48; Z= -1.58** **Concrete**	variety **Mean= 2.62; Z= 1.27** **Abstract**	idea **Mean= 2.71; Z= 1.50** **Abstract**	house **Mean= 1.56; Z= -1.38** **Concrete**	mind **Mean= 2.71; Z= 1.50** **Abstract**
bus **Mean= 1.59; Z= -1.30** **Concrete**	purpose **Mean= 2.73; Z= 1.55** **Abstract**	hand **Mean= 1.67; Z= -1.10** **Concrete**	paper **Mean= 1.63; Z= -1.20** **Concrete**	sun **Mean= 1.67; Z= -1.10** **Concrete**
progress **Mean= 2.66; Z= 1.37** **Abstract**	experience **Mean= 2.68; Z= 1.42** **Abstract**	success **Mean= 2.68; Z= 1.42** **Abstract**	car **Mean= 1.55; Z= -1.40** **Concrete**	influence **Mean= 2.68; Z= 1.42** **Abstract**
door **Mean= 1.62; Z= -1.23** **Concrete**	fish **Mean= 1.70; Z= -1.03** **Concrete**	concern **Mean= 2.62; Z= 1.27** **Abstract**	quality **Mean= 2.59; Z= 1.20** **Abstract**	book **Mean= 1.61; Z= -1.25** **Concrete**
courage **Mean= 2.66; Z= 1.37** **Abstract**	boat **Mean= 1.62; Z= -1.23** **Concrete**	horse **Mean= 1.64; Z= -1.18** **Concrete**	reason **Mean= 2.67; Z= 1.40** **Abstract**	dog **Mean= 1.63; Z= -1.20** **Concrete**
difference **Mean= 2.53; Z= 1.05** **Abstract**	bed **Mean= 1.65; Z= -1.15** **Concrete**	love **Mean= 2.80; Z= 1.72** **Abstract**	mountain **Mean= 1.63; Z= -1.20** **Concrete**	gun **Mean= 1.59; Z= -1.30** **Concrete**

cause **Mean= 2.63; Z= 1.30** **Abstract**	hair **Mean= 1.62; Z= -1.23** **Concrete**	fear **Mean= 2.64; Z= 1.32** **Abstract**	bird **Mean= 1.66; Z= -1.13** **Concrete**	wood **Mean= 1.67; Z= -1.10** **Concrete**
wish **Mean= 2.72; Z= 1.52** **Abstract**	thought **Mean= 2.74; Z= 1.57** **Abstract**	hope **Mean= 2.78; Z= 1.67** **Abstract**	style **Mean= 2.67; Z= 1.40** **Abstract**	television **Mean= 1.65; Z= -1.15** **Concrete**
corn **Mean= 1.65; Z= -1.15** **Concrete**	value **Mean= 2.70; Z= 1.47** **Abstract**	peace **Mean= 2.67; Z= 1.40** **Abstract**	life **Mean= 2.62; Z= 1.27** **Abstract**	train **Mean= 1.65; Z= -1.15** **Concrete**
stone **Mean= 1.66; Z= -1.13** **Concrete**	sense **Mean= 2.65; Z= 1.35** **Abstract**	chance **Mean= 2.60; Z= 1.22** **Abstract**	cat **Mean= 1.56; Z= -1.38** **Concrete**	foot **Mean= 1.64; Z= -1.18** **Concrete**

25 concrete and 25 abstract pictures
(N= 113, Mean= 2.31, Std. Deviation= .48, z < -0.75; z > 0.84)

 **Mean= 1.94; Z= -0.87** **Concrete**	 **Mean= 1.99; Z= -0.75** **Concrete**	 **Mean= 1.54; Z= -1.80** **Concrete**	 **Mean= 1.75; Z= -1.31** **Concrete**	 **Mean= 2.67; Z= 0.84** **Abstract**
 **Mean= 1.63; Z= -1.59** **Concrete**	 **Mean= 1.50; Z= -1.90** **Concrete**	 **Mean= 1.76; Z= -1.29** **Concrete**	 **Mean= 1.57; Z= -1.73** **Concrete**	 **Mean= 2.85; Z= 1.26** **Abstract**
 **Mean= 2.88; Z= 1.33** **Abstract**	 **Mean= 2.74; Z= 1.00** **Abstract**	 **Mean= 1.83; Z= -1.12** **Concrete**	 **Mean= 1.53; Z= -1.83** **Concrete**	 **Mean= 1.77; Z= -1.26** **Concrete**
 **Mean= 1.64; Z= -1.57** **Concrete**	 **Mean= 2.74; Z= 1.00** **Abstract**	 **Mean= 1.69; Z= -1.45** **Concrete**	 **Mean= 1.53; Z= -1.83** **Concrete**	 **Mean= 2.93; Z= 1.45** **Abstract**

 **Mean= 2.96; Z= 1.52** **Abstract**	 **Mean= 3.15; Z= 1.96** **Abstract**	 **Mean= 1.97; Z= -0.80** **Concrete**	 **Mean= 1.94; Z= -0.87** **Concrete**	 **Mean= 2.74; Z= 1.00** **Abstract**
 **Mean= 1.80; Z= -1.19** **Concrete**	 **Mean= 1.84; Z= -1.10** **Concrete**	 **Mean= 2.77; Z= 1.07** **Abstract**	 **Mean= 3.18; Z= 2.03** **Abstract**	 **Mean= 3.05; Z= 1.73** **Abstract**
 **Mean= 1.66; Z= -1.52** **Concrete**	 **Mean= 2.70; Z= 0.91** **Abstract**	 **Mean= 3.12; Z= 1.89** **Abstract**	 **Mean= 3.03; Z= 1.68** **Abstract**	 **Mean= 2.80; Z= 1.14** **Abstract**
 **Mean= 2.77; Z= 1.07** **Abstract**	 **Mean= 1.74; Z= -1.34** **Concrete**	 **Mean= 2.70; Z= 0.91** **Abstract**	 **Mean= 1.82; Z= -1.15** **Concrete**	 **Mean= 3.27; Z= 2.24** **Abstract**
 **Mean= 3.03; Z= 1.68** **Abstract**	 **Mean= 1.63; Z= -1.59** **Concrete**	 **Mean= 2.92; Z= 1.42** **Abstract**	 **Mean= 2.69; Z= 0.89** **Abstract**	 **Mean= 3.11; Z= 1.87** **Abstract**
 **Mean= 3.05; Z= 1.73** **Abstract**	 **Mean= 1.86; Z= -1.05** **Concrete**	 **Mean= 1.86; Z= -1.05** **Concrete**	 **Mean= 1.91; Z= -0.94** **Concrete**	 **Mean= 3.16; Z= 1.99** **Abstract**

25 concrete and 25 abstract logograms
(N= 127, Mean= 2.09, Std. Deviation= .36, z < -0.57; z > 1.38)

木 **Mean= 1.84; Z= -0.68** **Concrete**	船 **Mean= 1.80; Z= -0.79** **Concrete**	德 **Mean= 2.65; Z= 1.55** **Abstract**	床 **Mean= 1.72; Z= -1.01** **Concrete**	犬 **Mean= 1.81; Z= -0.76** **Concrete**
林 **Mean= 1.85; Z= -0.65** **Concrete**	雨 **Mean= 1.84; Z= -0.68** **Concrete**	紙 **Mean= 1.82; Z= -0.73** **Concrete**	義 **Mean= 2.75; Z= 1.82** **Abstract**	惡 **Mean= 2.73; Z= 1.77** **Abstract**

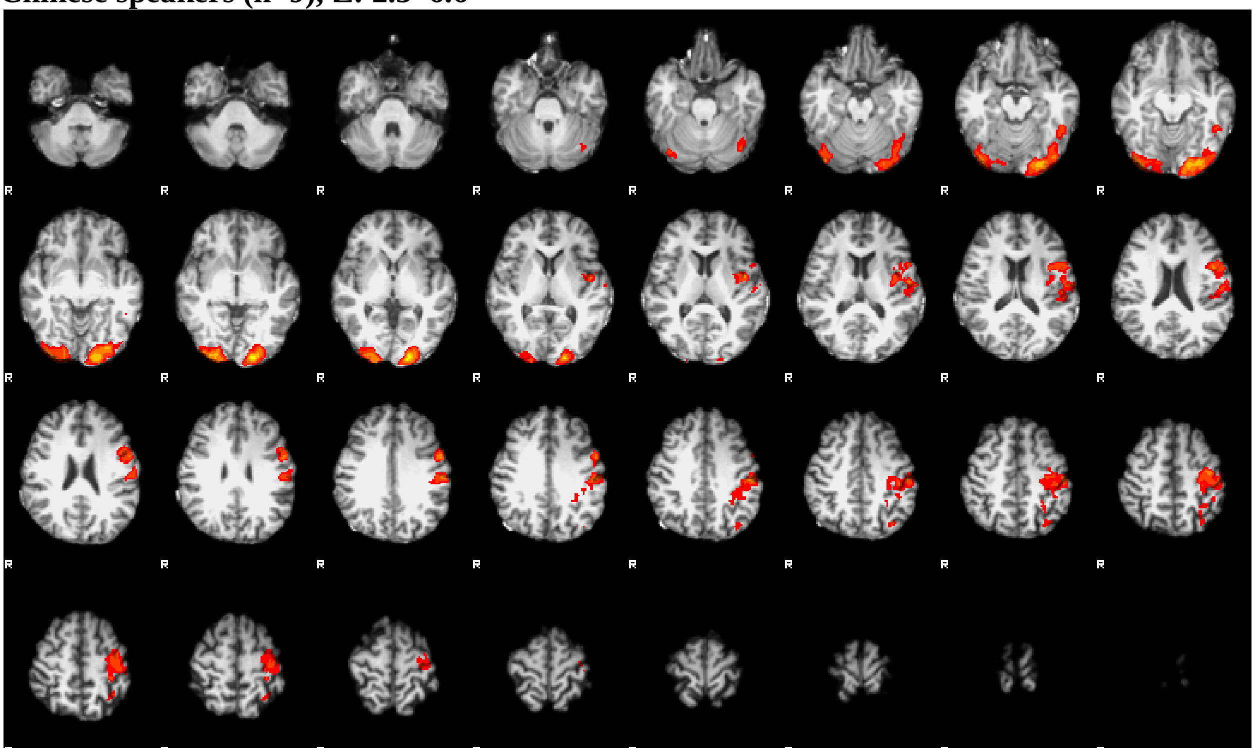
理 Mean= 2.68; Z= 1.63 Abstract	雪 Mean= 1.82; Z= -0.73 Concrete	筆 Mean= 1.84; Z= -0.68 Concrete	真 Mean= 2.67; Z= 1.60 Abstract	意 Mean= 2.72; Z= 1.74 Abstract
屋 Mean= 1.84; Z= -0.68 Concrete	米 Mean= 1.76; Z= -0.90 Concrete	書 Mean= 1.88; Z= -0.57 Concrete	利 Mean= 2.59; Z= 1.38 Abstract	手 Mean= 1.80; Z= -0.79 Concrete
花 Mean= 1.82; Z= -0.73 Concrete	馬 Mean= 1.76; Z= -0.90 Concrete	氣 Mean= 2.59; Z= 1.38 Abstract	山 Mean= 1.79; Z= -0.82 Concrete	難 Mean= 2.64; Z= 1.52 Abstract
善 Mean= 2.71; Z= 1.71 Abstract	無 Mean= 2.71; Z= 1.71 Abstract	草 Mean= 1.83; Z= -0.71 Concrete	福 Mean= 2.68; Z= 1.63 Abstract	權 Mean= 2.76; Z= 1.85 Abstract
牛 Mean= 1.85; Z= -0.65 Concrete	忠 Mean= 2.71; Z= 1.71 Abstract	布 Mean= 1.88; Z= -0.57 Concrete	水 Mean= 1.87; Z= -0.60 Concrete	美 Mean= 2.77; Z= 1.88 Abstract
孝 Mean= 2.59; Z= 1.38 Abstract	竹 Mean= 1.84; Z= -0.68 Concrete	愛 Mean= 2.77; Z= 1.88 Abstract	車 Mean= 1.82; Z= -0.73 Concrete	夢 Mean= 2.65; Z= 1.55 Abstract
人 Mean= 1.88; Z= -0.57 Concrete	仁 Mean= 2.78; Z= 1.90 Abstract	情 Mean= 2.69; Z= 1.66 Abstract	沙 Mean= 1.84; Z= -0.68 Abstract	智 Mean= 2.60; Z= 1.41 Abstract
門 Mean= 1.86; Z= -0.62 Concrete	麗 Mean= 2.61; Z= 1.44 Abstract	因 Mean= 2.68; Z= 1.63 Abstract	志 Mean= 2.74; Z= 1.79 Abstract	變 Mean= 2.68; Z= 1.63 Abstract

Appendix C: Analyses of fMRI Data

The following 13 sections present fMRI data in different contrasts. FMRI data processing was carried out using FEAT (FMRI Expert Analysis Tool) Version 5.98, part of FSL (FMRIB's Software Library, www.fmrib.ox.ac.uk/fsl). Z (Gaussianised T/F) statistic images were thresholded using clusters determined by Z>2.3 and a (corrected) cluster significance threshold of P=0.01 (Worsley, 2001). Significant activations in brain regions that are listed in the table of each section are identified according to 1) Harvard-Oxford Cortical Structural Atlas, and 2) Talairach Daemon Labels provided by fslview.

fMRI Data: Interpreting Different Semantics

Chinese speakers (n=9), Z: 2.3~6.6

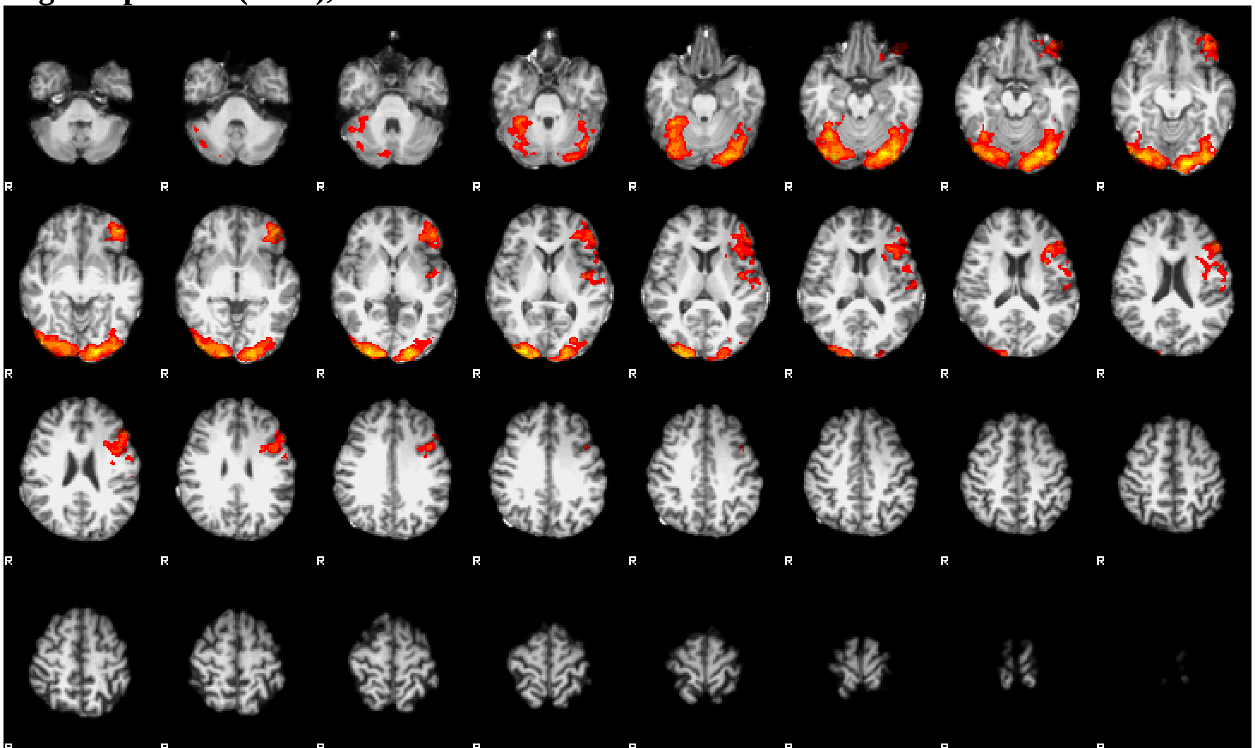


Cluster Index	Z	x	y	z	Brain Areas (Coordinate Space: MNI_152)
3.6	4.69	-42	-14	52	1. 53% Precentral Gyrus, 12% Postcentral Gyrus 2. Left Cerebrum.Parietal Lobe.Postcentral Gyrus.Gray Matter.**BA3**
3.5	4.6	-58	-18	32	1. 58% Postcentral Gyrus, 12% Supramarginal Gyrus, anterior division 2. Left Cerebrum.Parietal Lobe.Postcentral Gyrus.Gray Matter.**BA2**
3.4	4.54	-54	6	32	1. 50% Precentral Gyrus, 9% Inferior Frontal Gyrus, pars opercularis, 4% Middle Frontal Gyrus 2. Left Cerebrum.Frontal Lobe.Precentral Gyrus.Gray Matter.**BA6**
3.3	4.53	-54	-20	38	1. 52% Postcentral Gyrus, 10% Supramarginal Gyrus, anterior division 2. Left Cerebrum.Parietal Lobe.Postcentral Gyrus.White Matter.
3.2	4.51	-54	-20	48	1. 59% Postcentral Gyrus, 4% Supramarginal Gyrus, anterior division, 1% Precentral Gyrus 2. Left Cerebrum.Parietal Lobe.Postcentral Gyrus.Gray Matter.**BA2**
3.1	4.31	-46	8	20	1. 33% Inferior Frontal Gyrus, pars opercularis, 19% Precentral Gyrus

					2. Left Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
2.6	6.29	-18	-96	-2	1. 45% Occipital Pole, 3% Lateral Occipital Cortex, inferior division, 1% Occipital Fusiform Gyrus 2. Left Cerebrum.Occipital Lobe.Lingual Gyrus.White Matter.
2.5	6.16	-18	-98	-6	1. 51% Occipital Pole, 4% Lateral Occipital Cortex, inferior division 2. Left Cerebrum.Occipital Lobe.Inferior Occipital Gyrus.Gray Matter.**BA17**
2.4	5.75	-30	-86	-12	1. 23% Occipital Fusiform Gyrus, 20% Lateral Occipital Cortex, inferior division, 5% Occipital Pole 2. Left Cerebrum.Occipital Lobe.Fusiform Gyrus.Gray Matter.**BA19**
2.3	5.71	-26	-90	-14	1. 21% Occipital Fusiform Gyrus, 17% Lateral Occipital Cortex, inferior division, 15% Occipital Pole 2. Left Cerebrum.Occipital Lobe.Fusiform Gyrus.Gray Matter.**BA18**
2.2	5.48	-18	-90	-12	1. 29% Occipital Fusiform Gyrus, 19% Occipital Pole, 6% Lingual Gyrus, 5% Lateral Occipital Cortex, inferior division 2. Left Cerebrum.Occipital Lobe.Lingual Gyrus.
2.1	4.16	-42	-82	-16	1. 59% Lateral Occipital Cortex, inferior division, 10% Occipital Fusiform Gyrus 2. Left Cerebellum.Posterior Lobe.Declive.Gray Matter.
1.6	5.32	38	-92	-12	1. 22% Lateral Occipital Cortex, inferior division, 19% Occipital Pole, 1% Occipital Fusiform Gyrus 2. Right Cerebrum.Occipital Lobe.Inferior Occipital Gyrus.White Matter.
1.5	5.2	20	-100	-2	1. 62% Occipital Pole 2. Right Cerebrum.Occipital Lobe.Lingual Gyrus.White Matter.
1.4	5.18	26	-94	-4	1. 46% Occipital Pole, 7% Lateral Occipital Cortex, inferior division, 1% Lingual Gyrus 2. Right Cerebrum.Occipital Lobe.Lingual Gyrus.White Matter.
1.3	5.14	40	-88	-14	1. 41% Lateral Occipital Cortex, inferior division, 10% Occipital Pole, 4% Occipital Fusiform Gyrus 2. Right Cerebrum
1.2	4.35	20	-88	-6	1. 33% Occipital Fusiform Gyrus, 15% Occipital Pole, 9% Lingual Gyrus, 4% Lateral Occipital Cortex, inferior division 2. Right Cerebrum.Occipital Lobe.Lingual Gyrus.White Matter.
1.1	3.86	42	-74	-22	1. 9% Lateral Occipital Cortex, inferior division, 3% Occipital Fusiform Gyrus 2. Right Cerebellum.Posterior Lobe.Declive.Gray Matter.

In Chinese speakers, significant activations formed three clusters. The first cluster (3.6 ~ 3.1) is located in the left hemisphere that covers the Postcentral Gyrus, the Precentral Gyrus, the anterior division of the SMG, and the IFG, pars opercularis including BA 2, 3, and 6. The second cluster (2.6 ~ 2.1) is located in the left hemisphere that covers the Occipital Pole, the Occipital Fusiform Gyrus, and the inferior division of the Lateral Occipital Cortex including BA 17, 18, and 19. The third cluster (1.6 ~ 1.1) is located in the right hemisphere that covers the Occipital Pole, the inferior division of the Lateral Occipital Cortex, and the Occipital Fusiform Gyrus. The Chinese participants required the anterior division of the SMG and the IFG, pars opercularis in the left hemisphere to do the semantic judgment of concrete vs. abstract.

English speakers (n=10), Z: 2.3~6.6



Cluster Index	Z	x	y	z	Brain Areas (Coordinate Space: MNI_152)
2.6	6.65	-26	-82	-18	1. 55% Occipital Fusiform Gyrus, 5% Lingual Gyrus, 5% Lateral Occipital Cortex, inferior division 2. Left Cerebellum.Posterior Lobe.Declive.Gray Matter.
2.5	6.45	28	-96	2	1. 66% Occipital Pole, 3% Lateral Occipital Cortex, inferior division, 1% Lateral Occipital Cortex, superior division 2. Right Cerebrum.Occipital Lobe.Cuneus.White Matter.
2.4	6.38	-18	-94	-8	1. 42% Occipital Pole, 5% Occipital Fusiform Gyrus, 5% Lateral Occipital Cortex, inferior division, 3% Lingual Gyrus 2. Left Cerebrum.Occipital Lobe.Inferior Occipital Gyrus.White Matter.
2.3	6.37	-14	-92	-14	1. 38% Occipital Pole, 17% Occipital Fusiform Gyrus, 11% Lingual Gyrus, 2% Lateral Occipital Cortex, inferior division 2. Left Cerebrum
2.2	6.1	32	-84	-14	1. 31% Lateral Occipital Cortex, inferior division, 30% Occipital Fusiform Gyrus, 3% Occipital Pole 2. Right Cerebrum.Occipital Lobe.Fusiform Gyrus.White Matter.
2.1	5.96	-38	-86	-14	1. 56% Lateral Occipital Cortex, inferior division, 8% Occipital Fusiform Gyrus, 5% Occipital Pole 2. Left Cerebellum.Posterior Lobe.Declive.Gray Matter.
1.6	5.14	-40	46	-8	1. 55% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
1.5	4.75	-50	30	22	1. 35% Middle Frontal Gyrus, 32% Inferior Frontal Gyrus, pars triangularis, 3% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
1.4	4.24	-46	42	0	1. 80% Frontal Pole, 3% Inferior Frontal Gyrus, pars triangularis 2. Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.

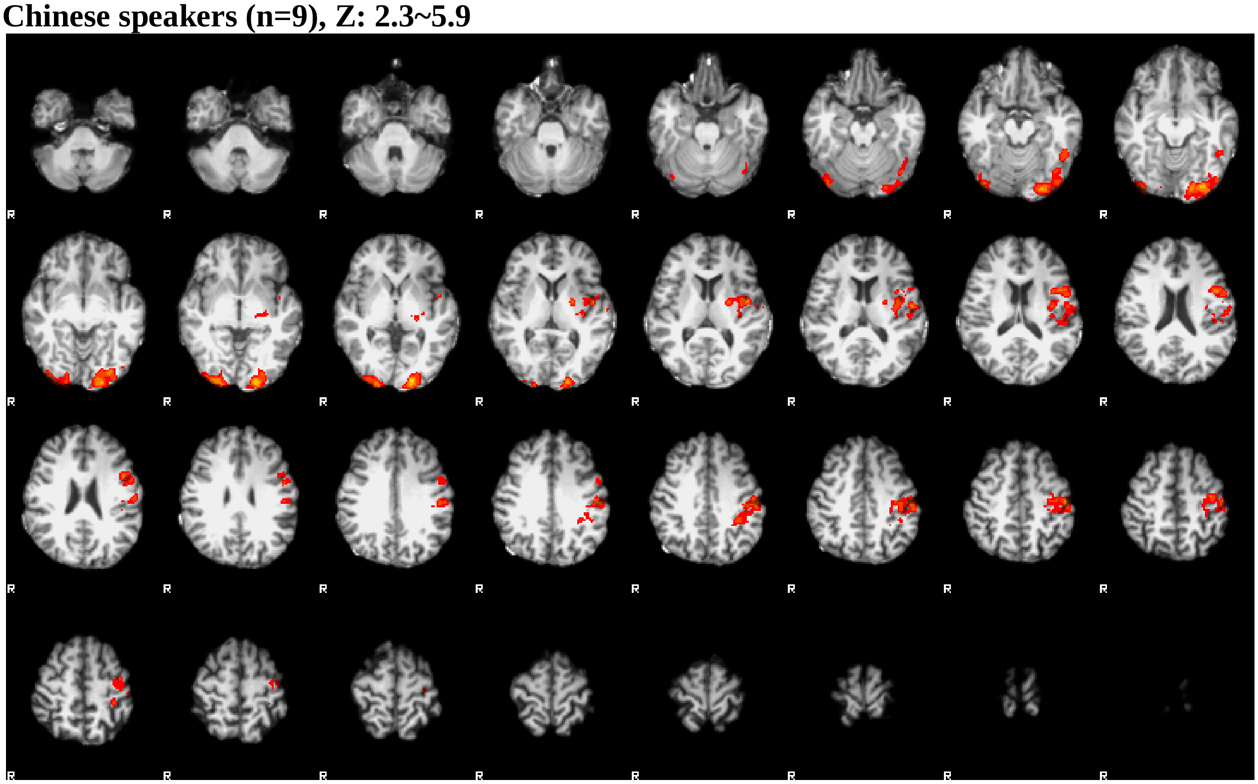
1.3	4.2	-34	26	12	1. 11% Frontal Operculum Cortex, 5% Inferior Frontal Gyrus, pars triangularis 2. Left Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
1.2	4.19	-36	38	-2	1. 5% Frontal Orbital Cortex, 2% Inferior Frontal Gyrus, pars triangularis, 1% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
1.1	4.12	-38	24	14	1. 4% Inferior Frontal Gyrus, pars triangularis, 2% Inferior Frontal Gyrus, pars opercularis, 1% Frontal Operculum Cortex, 1% Middle Frontal Gyrus 2. Left Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.

In English speakers, significant activations formed two clusters. The first cluster (2.6 ~ 2.1) is located in both right and left hemisphere that covers the Occipital Pole, the Occipital Fusiform Gyrus, and the inferior division of the Lateral Occipital Cortex. The second cluster (1.6 ~ 1.1) is located in the left hemisphere that covers the Frontal Pole, the MFG, the IFG, pars triangularis, and the Frontal Operculum Cortex. The English participants required the Frontal Pole, the MFG and the IFG, pars triangularis in the left hemisphere to do the semantic judgment of concrete vs. abstract.

As for group comparisons in this condition, English speakers had one cluster of significant activations in contrast to Chinese speakers. This cluster is located in the right hemisphere that covers the Occipital Pole, the Lingual Gyrus, the Occipital Fusiform Gyrus, and the inferior division of the Lateral Occipital Cortex including BA 18. These are areas associated with visual processing and are less significant findings. There are no significant activations that form clusters in the BOLD contrast of Chinese speakers vs. English speakers.

fMRI Data: Interpreting Concrete Stimuli

Chinese speakers (n=9), Z: 2.3~5.9

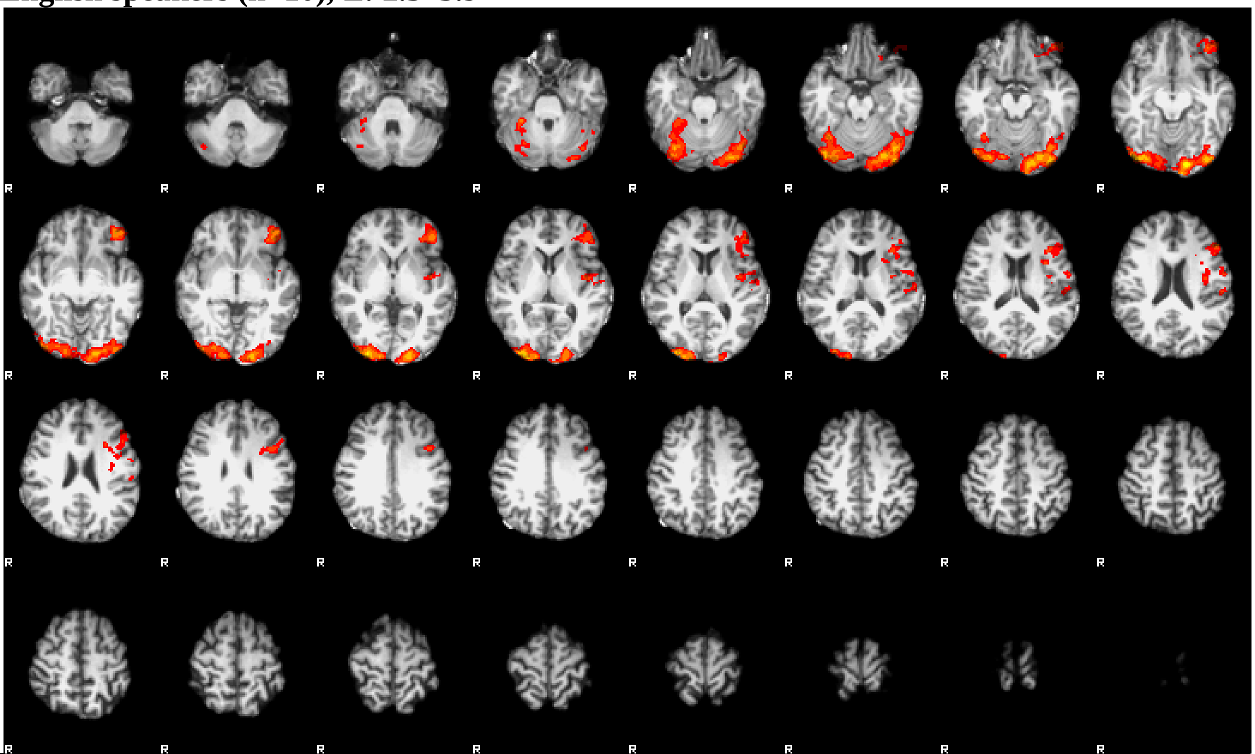


Cluster Index	Z	x	y	z	Brain Areas (Coordinate Space: MNI_152)
3.6	4.51	-54	-20	48	1. 59% Postcentral Gyrus, 4% Supramarginal Gyrus, anterior division, 1% Precentral Gyrus 2. Left Cerebrum.Parietal Lobe.Postcentral Gyrus.Gray Matter.**BA2**
3.5	4.3	-56	-8	12	1. 61% Central Opercular Cortex, 10% Postcentral Gyrus, 2% Planum Polare, 1% Planum Temporale, 1% Precentral Gyrus 2. Left Cerebrum.Frontal Lobe.Precentral Gyrus.Gray Matter.**BA43**
3.4	4.27	-46	-4	6	1. 71% Central Opercular Cortex, 3% Insular Cortex, 2% Planum Polare, 1% Heschl's Gyrus (includes H1 and H2) 2. Left Cerebrum.Frontal Lobe.Precentral Gyrus.
3.3	4.19	-46	10	20	1. 38% Inferior Frontal Gyrus, pars opercularis, 8% Precentral Gyrus 2. Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
3.2	4.11	-24	-4	6	1. No label found 2. Left Cerebrum.Sub-lobar.Lentiform Nucleus.Gray Matter.Putamen
3.1	4.07	-56	-22	40	1. 52% Postcentral Gyrus, 15% Supramarginal Gyrus, anterior division 2. Left Cerebrum.Parietal Lobe.Postcentral Gyrus.White Matter.
2.6	5.37	-18	-96	-2	1. 45% Occipital Pole, 3% Lateral Occipital Cortex, inferior division, 1% Occipital Fusiform Gyrus 2. Left Cerebrum.Occipital Lobe.Lingual Gyrus.White Matter.
2.5	5.01	-30	-86	-12	1. 23% Occipital Fusiform Gyrus, 20% Lateral Occipital Cortex, inferior division, 5% Occipital Pole 2. Left Cerebrum.Occipital Lobe.Fusiform Gyrus.Gray Matter.**BA19**
2.4	4.71	-24	-90	-16	1. 28% Occipital Fusiform Gyrus, 21% Occipital Pole, 14% Lateral Occipital Cortex, inferior division, 1% Lingual Gyrus 2. Left Cerebrum.Occipital Lobe.Fusiform Gyrus.Gray Matter.**BA18**
2.3	4.26	-18	-90	-14	1. 34% Occipital Fusiform Gyrus, 19% Occipital Pole, 7% Lingual Gyrus, 4% Lateral Occipital Cortex, inferior division 2. Left Cerebrum
2.2	3.88	-52	-48	-14	1. 40% Inferior Temporal Gyrus, temporooccipital part, 7% Inferior Temporal Gyrus, posterior division, 4% Middle Temporal Gyrus, temporooccipital part, 3% Middle Temporal Gyrus, posterior division, 1% Temporal Occipital Fusiform Cortex 2. Left Cerebrum.Temporal Lobe.Fusiform Gyrus.Gray Matter.**BA37**
2.1	3.77	-26	-88	-4	1. 18% Lateral Occipital Cortex, inferior division, 11% Occipital Fusiform Gyrus, 6% Occipital Pole 2. Left Cerebrum.Occipital Lobe.Lingual Gyrus.White Matter.
1.6	4.47	34	-96	-6	1. 51% Occipital Pole, 7% Lateral Occipital Cortex, inferior division 2. Right Cerebrum.Occipital Lobe.Inferior Occipital Gyrus.Gray Matter.**BA18**
1.5	4.33	20	-100	-2	1. 62% Occipital Pole 2. Right Cerebrum.Occipital Lobe.Lingual Gyrus.White Matter.
1.4	4.25	38	-92	-10	1. 29% Occipital Pole, 25% Lateral Occipital Cortex, inferior division, 1% Occipital Fusiform Gyrus 2. Right Cerebrum.Occipital Lobe.Inferior Occipital Gyrus.White Matter.
1.3	4.25	24	-98	-2	1. 64% Occipital Pole, 1% Lateral Occipital Cortex, inferior division 2. Right Cerebrum.Occipital Lobe.Lingual Gyrus.White Matter.
1.2	4.1	44	-84	-18	1. 27% Lateral Occipital Cortex, inferior division 2. Right Cerebellum.Posterior Lobe.Declive.Gray Matter.
1.1	4.03	42	-86	-14	1. 56% Lateral Occipital Cortex, inferior division, 4% Occipital Pole, 3% Occipital Fusiform Gyrus 2. Right Cerebrum

In Chinese speakers, significant activations formed three clusters. The first cluster (3.6 ~ 3.1) is located in the left hemisphere that covers the Postcentral Gyrus, the Central Opercular Cortex, the anterior division of the SMG, and the IFG, pars opercularis including BA 2 and 43. The second cluster (2.6 ~ 2.1) is located in the left hemisphere that covers the Occipital Pole, the Occipital Fusiform Gyrus, the inferior division of Lateral Occipital Cortex, and the temporooccipital part of the ITG including 19, 18, and 37. The third cluster (1.6 ~ 1.1) is located in the right hemisphere that covers the Occipital Pole, and the inferior division of the Lateral Occipital Cortex including BA 18.

Other than visual cortexes, the Chinese participants required the anterior division of the SMG and the IFG, pars opercularis in the left hemisphere to interpret concrete stimuli.

English speakers (n=10), Z: 2.3~5.9



Cluster Index	Z	x	y	z	Brain Areas (Coordinate Space: MNI_152)
2.6	5.96	-14	-92	-14	1. 38% Occipital Pole, 17% Occipital Fusiform Gyrus, 11% Lingual Gyrus, 2% Lateral Occipital Cortex, inferior division 2. Left Cerebrum
2.5	5.65	30	-96	2	1. 69% Occipital Pole, 4% Lateral Occipital Cortex, inferior division 2. Right Cerebrum.Occipital Lobe.Cuneus.White Matter.
2.4	5.33	-24	-82	-18	1. 52% Occipital Fusiform Gyrus, 6% Lingual Gyrus, 4% Lateral Occipital Cortex, inferior division 2. Left Cerebellum.Posterior Lobe.Declive.Gray Matter.
2.3	5.21	42	-86	-12	1. 60% Lateral Occipital Cortex, inferior division, 8% Occipital Pole, 1% Occipital Fusiform Gyrus 2. Right Cerebrum.Occipital Lobe.Inferior Occipital Gyrus.Gray Matter.**BA18**
2.2	5.19	-16	-98	-2	1. 52% Occipital Pole 2. Left Cerebrum.Occipital Lobe.Lingual Gyrus.White Matter.
2.1	5.19	34	-94	6	1. 59% Occipital Pole, 8% Lateral Occipital Cortex, inferior division,

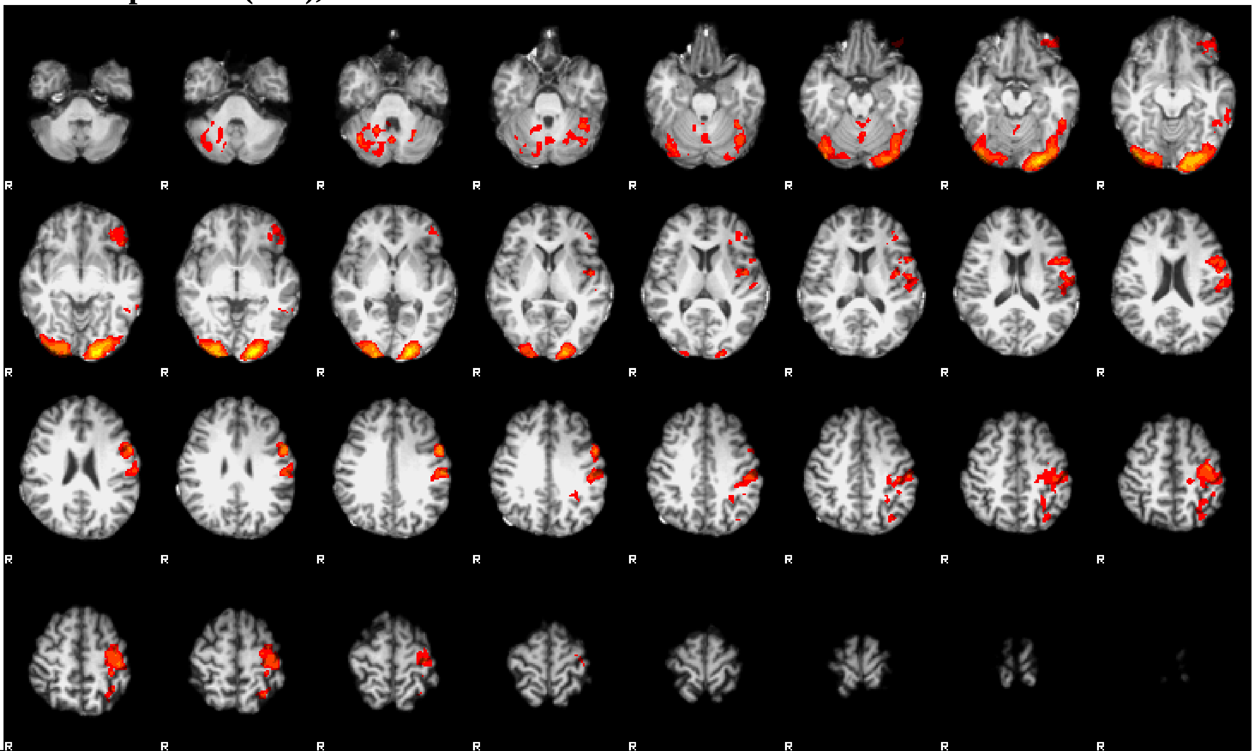
					4% Lateral Occipital Cortex, superior division 2. Right Cerebrum.Occipital Lobe.Middle Occipital Gyrus.Gray Matter.**BA18**
1.6	4.54	-40	46	-8	1. 55% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
1.5	4.05	-46	42	2	1. 85% Frontal Pole, 3% Inferior Frontal Gyrus, pars triangularis 2. Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
1.4	3.99	-44	38	-2	1. 30% Frontal Pole, 8% Inferior Frontal Gyrus, pars triangularis, 6% Frontal Orbital Cortex 2. Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
1.3	3.95	-50	32	20	1. 32% Inferior Frontal Gyrus, pars triangularis, 30% Middle Frontal Gyrus, 11% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
1.2	3.95	-36	38	-4	1. 7% Frontal Orbital Cortex, 4% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
1.1	3.77	-40	12	30	1. 36% Middle Frontal Gyrus, 15% Inferior Frontal Gyrus, pars opercularis, 11% Precentral Gyrus 2. Left Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.

In English speakers, significant activations formed two clusters. The first cluster (2.6 ~ 2.1) is located in both right and left hemisphere that covers the Occipital Pole, the Occipital Fusiform Gyrus, and the inferior division of the Lateral Occipital Cortex including BA 18. The second cluster (1.6 ~ 1.1) is located in the left hemisphere that covers the Frontal Pole, the MFG, and the IFG. Other than visual cortexes, the English participants required the Frontal Pole, the MFG and the IFG in the left hemisphere to interpret concrete stimuli.

As for the group comparison, English speakers had one cluster of significant activations in contrast to Chinese speakers. This cluster is located in the right hemisphere that covers the Occipital Pole, and Temporal Occipital Fusiform Cortex. These are visual cortexes and less significant findings. There are no significant activations that form clusters in the contrast of Chinese speakers vs. English speakers. It is implied that there were no significant differences between the Chinese and English participants in using brain areas to interprete concrete stimuli.

fMRI Data: Interpreting Abstract Stimuli

Chinese speakers (n=9), Z: 2.3~7.0

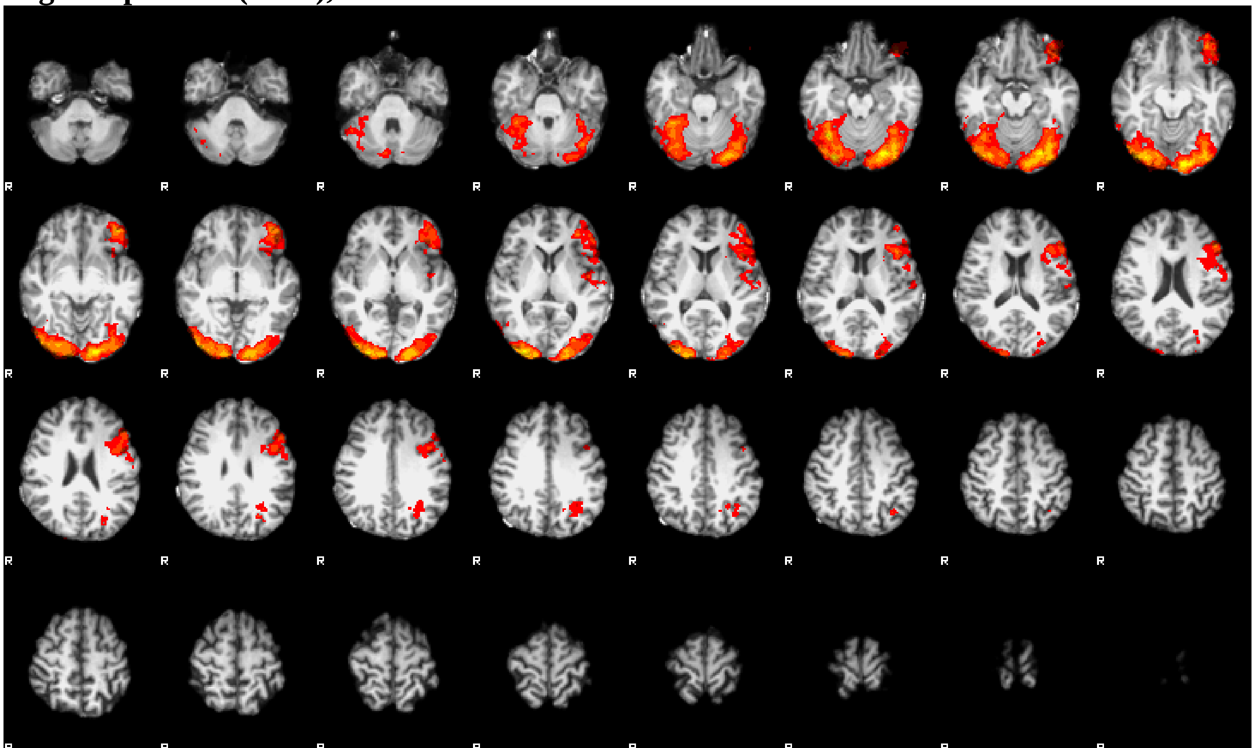


Cluster Index	Z	x	y	z	Brain Areas (Coordinate Space: MNI_152)
4.6	5.18	-54	6	32	1. 50% Precentral Gyrus, 9% Inferior Frontal Gyrus, pars opercularis, 4% Middle Frontal Gyrus 2. Left Cerebrum.Frontal Lobe.Precentral Gyrus.Gray Matter.**BA6**
4.5	4.73	-40	-14	54	1. 54% Precentral Gyrus, 4% Postcentral Gyrus 2. Left Cerebrum.Parietal Lobe.Precentral Gyrus.
4.4	4.71	-58	-20	30	1. 54% Postcentral Gyrus, 22% Supramarginal Gyrus, anterior division 2. Left Cerebrum.Parietal Lobe.Inferior Parietal Lobule.White Matter.
4.3	4.51	-44	-24	54	1. 43% Postcentral Gyrus, 11% Precentral Gyrus 2. Left Cerebrum.Parietal Lobe.Postcentral Gyrus.White Matter.
4.2	4.22	-34	-18	54	1. 26% Precentral Gyrus, 2% Postcentral Gyrus 2. Left Cerebrum.Frontal Lobe.Precentral Gyrus.White Matter.
4.1	4.17	-52	-20	36	1. 44% Postcentral Gyrus, 9% Supramarginal Gyrus, anterior division 2. Left Cerebrum.Parietal Lobe.Postcentral Gyrus.White Matter.
3.6	6.89	-20	-98	-6	1. 53% Occipital Pole, 4% Lateral Occipital Cortex, inferior division 2. Left Cerebrum.Occipital Lobe.Inferior Occipital Gyrus.Gray Matter.**BA17**
3.5	6.76	-20	-96	-2	1. 48% Occipital Pole, 5% Lateral Occipital Cortex, inferior division 2. Left Cerebrum.Occipital Lobe.Lingual Gyrus.White Matter.
3.4	6.31	-26	-90	-14	1. 21% Occipital Fusiform Gyrus, 17% Lateral Occipital Cortex, inferior division, 15% Occipital Pole 2. Left Cerebrum.Occipital Lobe.Fusiform Gyrus.Gray Matter.**BA18**
3.3	6.12	-18	-90	-12	1. 29% Occipital Fusiform Gyrus, 19% Occipital Pole, 6% Lingual Gyrus, 5% Lateral Occipital Cortex, inferior division 2. Left Cerebrum.Occipital Lobe.Lingual Gyrus.

3.2	4.7	-40	-80	-18	1. 47% Lateral Occipital Cortex, inferior division, 21% Occipital Fusiform Gyrus 2. Left Cerebellum.Posterior Lobe.Declive.Gray Matter.
3.1	4.49	-38	-50	-26	1. 13% Temporal Occipital Fusiform Cortex, 4% Temporal Fusiform Cortex, posterior division, 1% Inferior Temporal Gyrus, temporooccipital part 2. Left Cerebellum.Anterior Lobe.Culmen.Gray Matter.
2.6	5.94	26	-94	-4	1. 46% Occipital Pole, 7% Lateral Occipital Cortex, inferior division, 1% Lingual Gyrus 2. Right Cerebrum.Occipital Lobe.Lingual Gyrus.White Matter.
2.5	5.68	40	-90	-14	1. 24% Lateral Occipital Cortex, inferior division, 11% Occipital Pole, 2% Occipital Fusiform Gyrus 2. Right Cerebrum
2.4	5.62	20	-98	-2	1. 53% Occipital Pole, 1% Lateral Occipital Cortex, inferior division 2. Right Cerebrum.Occipital Lobe.Lingual Gyrus.White Matter.
2.3	5.17	36	-92	-4	1. 47% Occipital Pole, 23% Lateral Occipital Cortex, inferior division 2. Right Cerebrum.Occipital Lobe.Inferior Occipital Gyrus.White Matter.
2.2	4.85	30	-86	-12	1. 32% Occipital Fusiform Gyrus, 14% Occipital Pole, 14% Lateral Occipital Cortex, inferior division 2. Right Cerebrum.Occipital Lobe.Fusiform Gyrus.Gray Matter.**BA19**
2.1	4.48	42	-76	-20	1. 25% Lateral Occipital Cortex, inferior division, 4% Occipital Fusiform Gyrus 2. Right Cerebellum.Posterior Lobe.Declive.Gray Matter.
1.6	3.66	-46	44	-10	1. 88% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
1.5	3.55	-46	30	-8	1. 47% Frontal Orbital Cortex, 16% Inferior Frontal Gyrus, pars triangularis, 4% Frontal Pole, 2% Frontal Operculum Cortex 2. Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
1.4	3.55	-38	36	-6	1. 14% Frontal Orbital Cortex, 6% Frontal Pole, 1% Inferior Frontal Gyrus, pars triangularis 2. Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
1.3	3.4	-40	46	-14	1. 77% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
1.2	3.31	-48	44	-6	1. 88% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
1.1	3.26	-36	42	-8	1. 29% Frontal Pole, 1% Frontal Orbital Cortex 2. Left Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.

In Chinese speakers, significant activations formed four clusters. The first cluster (4.6 ~ 4.1) is located in the left hemisphere that covers the Precentral Gyrus, the Postcentral Gyrus, and the anterior division of the SMG including BA 6. The second cluster (3.6 ~ 3.1) is located in the left hemisphere that covers the Occipital Pole, the Occipital Fusiform Gyrus, the inferior division of the Lateral Occipital Cortex, and the Temporal Occipital Fusiform Cortex including BA 17 and 18. The third cluster (2.6 ~ 2.1) is located in the right hemisphere that covers the Occipital Pole, the inferior division of the Lateral Occipital Cortex, and the Occipital Fusiform Gyrus including BA 19. The forth cluster (1.6 ~ 1.1) is located in the left hemisphere that covers the Frontal Pole, the Frontal Orbital Cortex, the IFG, triangularis. Other than visual cortexes, the Chinese participants required the anterior division of the SMG, the Frontal Pole and the IFG, pars triangularis in the left hemisphere to interpret abstract stimuli.

English speakers (n=10), Z: 2.3~7.0



Cluster Index	Z	x	y	z	Brain Areas (Coordinate Space: MNI_152)
2.6	7.07	-26	-82	-20	1. 32% Occipital Fusiform Gyrus, 5% Lingual Gyrus, 4% Lateral Occipital Cortex, inferior division 2. Left Cerebellum.Posterior Lobe.Declive.Gray Matter.
2.5	6.91	-12	-94	-12	1. 54% Occipital Pole, 7% Occipital Fusiform Gyrus, 5% Lingual Gyrus, 2% Lateral Occipital Cortex, inferior division 2. Left Cerebrum.Occipital Lobe.Lingual Gyrus.White Matter.
2.4	6.65	-18	-94	-8	1. 42% Occipital Pole, 5% Occipital Fusiform Gyrus, 5% Lateral Occipital Cortex, inferior division, 3% Lingual Gyrus 2. Left Cerebrum.Occipital Lobe.Inferior Occipital Gyrus.White Matter.
2.3	6.48	30	-96	2	1. 69% Occipital Pole, 4% Lateral Occipital Cortex, inferior division 2. Right Cerebrum.Occipital Lobe.Cuneus.White Matter.
2.2	6.43	32	-86	-18	1. 28% Lateral Occipital Cortex, inferior division, 22% Occipital Fusiform Gyrus, 5% Occipital Pole 2. Right Cerebellum.Posterior Lobe.Declive.Gray Matter.
2.1	6.43	32	-84	-14	1. 31% Lateral Occipital Cortex, inferior division, 30% Occipital Fusiform Gyrus, 3% Occipital Pole 2. Right Cerebrum.Occipital Lobe.Fusiform Gyrus.White Matter.
1.6	5.5	-40	48	-6	1. 66% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
1.5	4.65	-42	22	14	1. 15% Inferior Frontal Gyrus, pars triangularis, 5% Inferior Frontal Gyrus, pars opercularis 2. Left Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
1.4	4.63	-50	30	22	1. 35% Middle Frontal Gyrus, 32% Inferior Frontal Gyrus, pars triangularis, 3% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
1.3	4.36	-32	42	4	1. 7% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.

1.2	4.25	-46	38	-4	1. 39% Frontal Pole, 10% Frontal Orbital Cortex, 8% Inferior Frontal Gyrus, pars triangularis 2. Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
1.1	4.06	-44	8	26	1. 30% Inferior Frontal Gyrus, pars opercularis, 25% Precentral Gyrus, 4% Middle Frontal Gyrus 2. Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.

In English speakers, significant activations formed two clusters. The first cluster (2.6 ~ 2.1) is located in both the right and left hemispheres that covers the Occipital Pole, Occipital Fusiform Gyrus, and the inferior division of the Lateral Occipital Cortex. The second cluster (1.6 ~ 1.1) is located in the left hemisphere that covers the Frontal Pole, the MFG, the IFG, and the Precentral Gyrus. Other than visual cortexes, the English participants required the Frontal Pole, the MFG, and the IFG in the left hemisphere to interpret abstract stimuli.

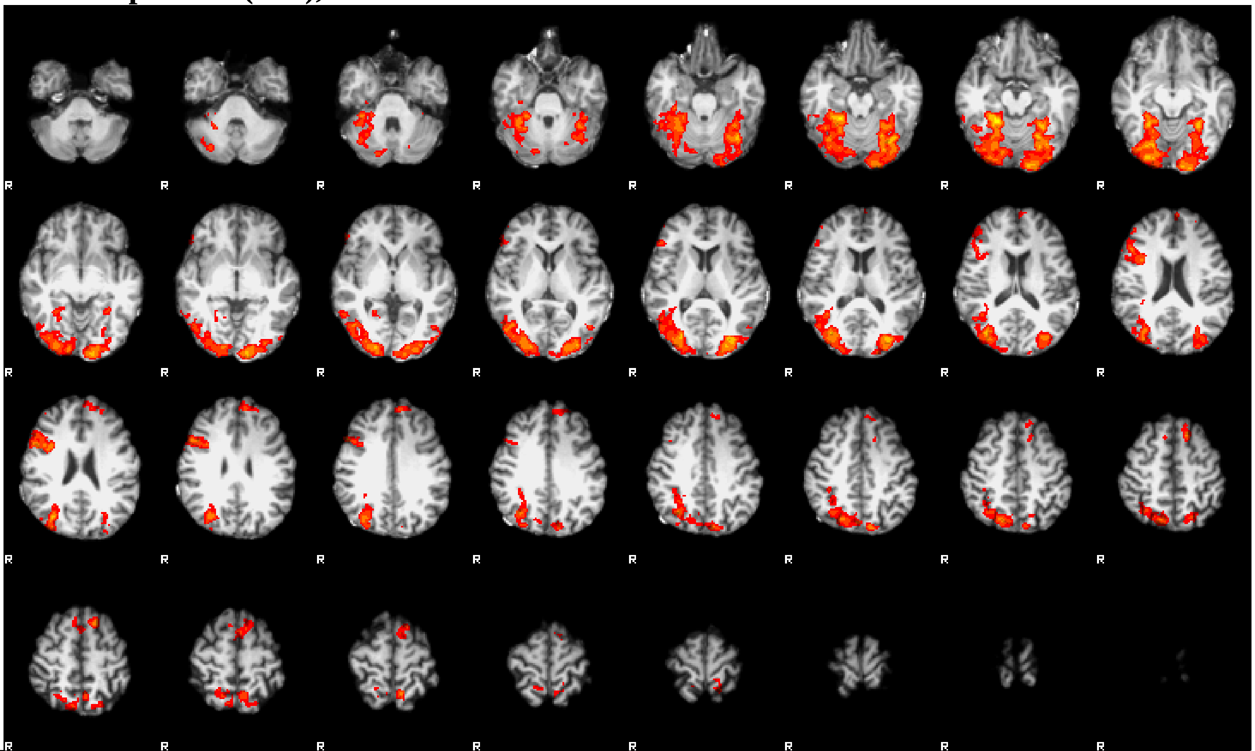
As for the group comparisons, Chinese speakers had one cluster of significant activations in contrast to English speakers. This cluster is located in the right hemisphere that covers the Postcentral Gyrus, the anterior division of the SMG, and the Superior Parietal Lobule including BA 5. In contrast to English speakers, the Chinese participants required additional resources in the right anterior division of the SMG to interpret abstract stimuli. On the other hand, English speakers had one cluster of significant activations in contrast to Chinese speakers. This cluster is located in the right hemisphere that covers the Occipital Pole, the Temporal Occipital Fusiform Cortex, the Occipital Fusiform Gyrus, and the inferior division of the Lateral Occipital Cortex. These areas are within the visual cortexes and less significant findings.

fMRI Data: Concrete vs. Abstract

No clusters were found in either Chinese speakers or English speakers. This implied that there were no significant differences in differentiating concrete stimuli from abstract stimuli in the brains of our English and Chinese participants. As for the group comparisons, there were also no clusters found in either Chinese speakers vs. English speakers or English speakers vs. Chinese speakers—it is implied that there were no significant differences between the Chinese and English participants in using brain areas to differentiate concrete stimuli from abstract stimuli.

fMRI Data: Abstract vs. Concrete

Chinese speakers (n=9), Z: 2.3~5.6

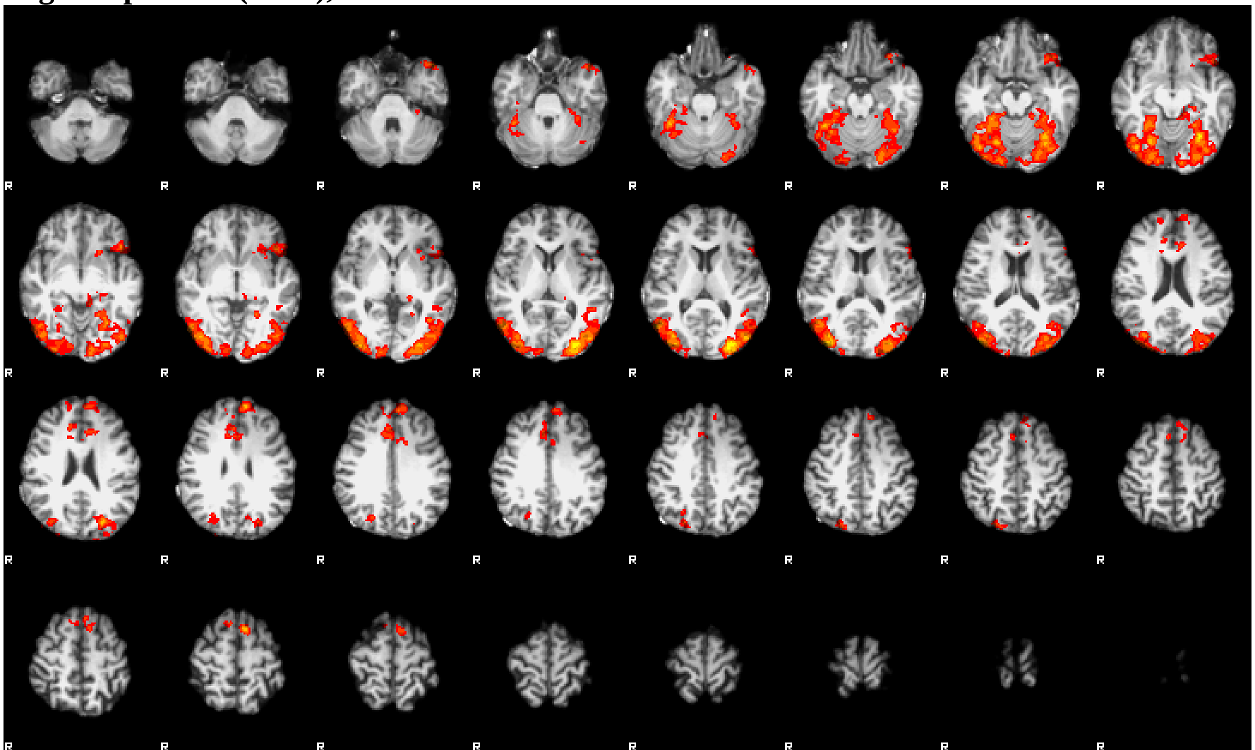


Cluster Index	Z	x	y	z	Brain Areas (Coordinate Space: MNI_152)
4.6	5.34	26	-42	-18	1. 65% Temporal Occipital Fusiform Cortex, 18% Temporal Fusiform Cortex, posterior division, 3% Lingual Gyrus 2. Right Cerebellum.Anterior Lobe.Culmen.Gray Matter.
4.5	4.9	32	-40	-18	1. 33% Temporal Occipital Fusiform Cortex, 26% Temporal Fusiform Cortex, posterior division 2. Right Cerebrum.Temporal Lobe.Fusiform Gyrus.Gray Matter.**BA20**
4.4	4.83	22	-90	2	1. 20% Occipital Pole, 4% Occipital Fusiform Gyrus, 4% Lateral Occipital Cortex, inferior division, 1% Lingual Gyrus, 1% Intracalcarine Cortex 2. Right Cerebrum.Occipital Lobe.Lingual Gyrus.White Matter.
4.3	4.7	24	-72	-14	1. 66% Occipital Fusiform Gyrus, 12% Lingual Gyrus 2. Right Cerebellum.Posterior Lobe.Declive.Gray Matter.
4.2	4.61	36	-76	14	1. 25% Lateral Occipital Cortex, superior division, 15% Lateral Occipital Cortex, inferior division 2. Right Cerebrum.Occipital Lobe.Middle Occipital Gyrus.White Matter.
4.1	4.61	30	-88	-12	1. 25% Occipital Fusiform Gyrus, 20% Occipital Pole, 17% Lateral Occipital Cortex, inferior division 2. Right Cerebrum.Occipital Lobe.Fusiform Gyrus.Gray Matter.**BA19**
3.6	4.95	-30	-52	-14	1. 50% Temporal Occipital Fusiform Cortex, 5% Temporal Fusiform Cortex, posterior division, 3% Lingual Gyrus 2. Left Cerebellum.Anterior Lobe.Culmen.Gray Matter.
3.5	4.94	-36	-66	-22	1. 11% Occipital Fusiform Gyrus, 11% Temporal Occipital Fusiform Cortex 2. Left Cerebellum.Posterior Lobe.Declive.Gray Matter.

3.4	4.93	-32	-82	10	1. 23% Lateral Occipital Cortex, superior division, 13% Lateral Occipital Cortex, inferior division 2. Left Cerebrum.Occipital Lobe.Middle Occipital Gyrus.White Matter.
3.3	4.63	-24	-62	-16	1. 33% Temporal Occipital Fusiform Cortex, 17% Occipital Fusiform Gyrus, 8% Lingual Gyrus 2. Left Cerebellum.Posterior Lobe.Declive.Gray Matter.
3.2	4.5	-24	-90	8	1. 14% Occipital Pole, 9% Lateral Occipital Cortex, superior division, 7% Lateral Occipital Cortex, inferior division 2. Left Cerebrum.Occipital Lobe.Middle Occipital Gyrus.White Matter.
3.1	4.5	-16	-96	-18	1. 34% Occipital Pole, 4% Lateral Occipital Cortex, inferior division, 3% Occipital Fusiform Gyrus, 1% Lingual Gyrus 2. Left Cerebrum
2.6	4.29	36	10	22	1. 4% Inferior Frontal Gyrus, pars opercularis, 2% Precentral Gyrus, 1% Middle Frontal Gyrus 2. Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
2.5	4.13	54	14	24	1. 55% Inferior Frontal Gyrus, pars opercularis, 14% Precentral Gyrus, 2% Middle Frontal Gyrus 2. Right Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.Gray Matter.**BA9**
2.4	4.05	54	20	30	1. 28% Middle Frontal Gyrus, 22% Inferior Frontal Gyrus, pars opercularis, 6% Inferior Frontal Gyrus, pars triangularis, 3% Precentral Gyrus 2. Right Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
2.3	3.87	46	18	26	1. 35% Inferior Frontal Gyrus, pars opercularis, 22% Middle Frontal Gyrus, 3% Precentral Gyrus, 2% Inferior Frontal Gyrus, pars triangularis 2. Right Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
2.2	3.76	44	14	26	1. 31% Inferior Frontal Gyrus, pars opercularis, 12% Middle Frontal Gyrus, 10% Precentral Gyrus 2. Right Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
2.1	3.72	50	24	20	1. 21% Inferior Frontal Gyrus, pars triangularis, 15% Inferior Frontal Gyrus, pars opercularis, 7% Middle Frontal Gyrus, 2% Precentral Gyrus 2. Right Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
1.6	4.04	-16	24	56	1. 45% Superior Frontal Gyrus, 2% Middle Frontal Gyrus 2. Left Cerebrum.Frontal Lobe.Superior Frontal Gyrus.Gray Matter.**BA6**
1.5	3.67	-8	56	30	1. 27% Frontal Pole, 20% Superior Frontal Gyrus 2. Left Cerebrum.Frontal Lobe.Superior Frontal Gyrus.White Matter.
1.4	3.3	-16	20	64	1. 44% Superior Frontal Gyrus, 1% Middle Frontal Gyrus 2. Left Cerebrum.Frontal Lobe.Middle Frontal Gyrus.Gray Matter.**BA6**
1.3	3.17	-4	62	20	1. 79% Frontal Pole, 2% Superior Frontal Gyrus 2. Left Cerebrum.Frontal Lobe.Superior Frontal Gyrus.White Matter.
1.2	3.13	-6	10	62	1. 25% Superior Frontal Gyrus, 10% Juxtapositional Lobule Cortex (formerly Supplementary Motor Cortex) 2. Left Cerebrum.Frontal Lobe.Medial Frontal Gyrus.
1.1	3.11	0	12	58	1. 30% Superior Frontal Gyrus, 6% Paracingulate Gyrus, 6% Juxtapositional Lobule Cortex (formerly Supplementary Motor Cortex) 2. Left Cerebrum.Frontal Lobe.Superior Frontal Gyrus.

In Chinese speakers, significant activations formed four clusters. The first cluster (4.6 ~ 4.1) is located in the right hemisphere that covers the Occipital Pole, the Temporal Occipital Fusiform Cortex, the Occipital Fusiform Gyrus, the Lateral Occipital Cortex, and the posterior division of the Temporal Fusiform Cortex including BA 19 and 20. The second cluster (3.6 ~ 3.1) is located in the left hemisphere that covers the Temporal Occipital Fusiform Cortex, the Occipital Pole, the Occipital Fusiform Gyrus, and the Lateral Occipital Cortex. The third cluster (2.6 ~ 2.1) is located in the right hemisphere that covers the IFG, the MFG, and the Precentral Gyrus including BA 9. The forth cluster (1.6 ~ 1.1) is located in the left hemisphere that covers the SFG, the Frontal Pole, and the SMC including BA 6. The Chinese participants required activations in the right IFG, the right MFG, the left SFG, and the left Frontal Pole to differentiate abstract stimuli from concrete stimuli.

English speakers (n=10), Z: 2.3~5.6



Cluster Index	Z	x	y	z	Brain Areas (Coordinate Space: MNI_152)
5.6	4.74	44	-84	16	1. 52% Lateral Occipital Cortex, superior division, 11% Lateral Occipital Cortex, inferior division, 2% Occipital Pole 2. Right Cerebrum.Occipital Lobe.Middle Occipital Gyrus.Gray Matter.**BA19**
5.5	4.73	26	-68	-14	1. 63% Occipital Fusiform Gyrus, 11% Lingual Gyrus, 4% Temporal Occipital Fusiform Cortex 2. Right Cerebellum.Posterior Lobe.Declive.Gray Matter.
5.4	4.71	58	-66	8	1. 56% Lateral Occipital Cortex, inferior division, 5% Lateral Occipital Cortex, superior division, 4% Middle Temporal Gyrus, temporooccipital part 2. Right Cerebrum.Temporal Lobe.Middle Temporal Gyrus.Gray Matter.**BA37**
5.3	4.66	36	-86	12	1. 30% Lateral Occipital Cortex, superior division, 24% Lateral Occipital Cortex, inferior division, 17% Occipital Pole 2. Right Cerebrum.Occipital Lobe.Middle Occipital Gyrus.Gray Matter.**BA19**
5.2	4.65	42	-50	-20	1. 63% Temporal Occipital Fusiform Cortex, 6% Inferior Temporal Gyrus, temporooccipital part

					2. Right Cerebrum.Temporal Lobe.Fusiform Gyrus.Gray Matter.**BA37**
5.1	4.59	38	-78	8	1. 37% Lateral Occipital Cortex, inferior division, 16% Lateral Occipital Cortex, superior division 2. Right Cerebrum.Occipital Lobe.Middle Occipital Gyrus.White Matter.
4.6	5.61	-30	-86	6	1. 27% Lateral Occipital Cortex, inferior division, 16% Lateral Occipital Cortex, superior division, 5% Occipital Pole 2. Left Cerebrum.Occipital Lobe.Middle Occipital Gyrus.White Matter.
4.5	5.52	-30	-62	-12	1. 24% Temporal Occipital Fusiform Cortex, 18% Occipital Fusiform Gyrus, 5% Lingual Gyrus 2. Left Cerebellum.Posterior Lobe.Declive.Gray Matter.
4.4	4.66	-32	-70	-14	1. 52% Occipital Fusiform Gyrus, 3% Temporal Occipital Fusiform Cortex, 3% Lateral Occipital Cortex, inferior division 2. Left Cerebellum.Posterior Lobe.Declive.Gray Matter.
4.3	4.6	-46	-80	6	1. 71% Lateral Occipital Cortex, inferior division, 8% Lateral Occipital Cortex, superior division 2. Left Cerebrum.Occipital Lobe.Middle Occipital Gyrus.White Matter.
4.2	4.38	-26	-76	24	1. 49% Lateral Occipital Cortex, superior division 2. Left Cerebrum.Occipital Lobe.Precuneus.White Matter.
4.1	4.34	-40	-76	2	1. 47% Lateral Occipital Cortex, inferior division 2. Left Cerebrum.Occipital Lobe.Middle Occipital Gyrus.White Matter.
3.6	4.07	-46	24	-4	1. 43% Frontal Operculum Cortex, 27% Frontal Orbital Cortex, 4% Inferior Frontal Gyrus, pars triangularis, 2% Inferior Frontal Gyrus, pars opercularis 2. Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
3.5	3.86	-46	20	-30	1. 64% Temporal Pole 2. Left Cerebrum.Temporal Lobe.Superior Temporal Gyrus.Gray Matter.**BA38**
3.4	3.74	-42	22	-32	1. 59% Temporal Pole, 1% Frontal Orbital Cortex 2. Left Cerebrum
3.3	3.45	-20	20	-8	1. No label found 2. Left Cerebrum.Sub-lobar.Extra-Nuclear.White Matter.
3.2	3.42	-34	28	-16	1. 50% Frontal Orbital Cortex, 4% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
3.1	3.41	-54	20	-2	1. 20% Inferior Frontal Gyrus, pars opercularis, 19% Inferior Frontal Gyrus, pars triangularis, 4% Frontal Orbital Cortex, 1% Frontal Operculum Cortex 2. Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.Gray Matter.**BA47**
2.6	4.83	-8	18	60	1. 25% Superior Frontal Gyrus, 2% Juxtapositional Lobule Cortex (formerly Supplementary Motor Cortex) 2. Left Cerebrum.Frontal Lobe.Superior Frontal Gyrus.White Matter.
2.5	4.43	-10	58	28	1. 51% Frontal Pole, 6% Superior Frontal Gyrus 2. Left Cerebrum.Frontal Lobe.Superior Frontal Gyrus.White Matter.
2.4	3.18	-12	44	46	1. 71% Frontal Pole, 10% Superior Frontal Gyrus 2. Left Cerebrum.Frontal Lobe.Superior Frontal Gyrus.White Matter.
2.3	3.18	-4	30	56	1. 63% Superior Frontal Gyrus 2. Left Cerebrum.Frontal Lobe.Superior Frontal Gyrus.Gray Matter.**BA6**
2.2	3.11	14	56	22	1. 40% Frontal Pole 2. Right Cerebrum.Frontal Lobe.Superior Frontal Gyrus.White Matter.
2.1	3.1	-14	64	22	1. 73% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Superior Frontal Gyrus.Gray Matter.**BA9**

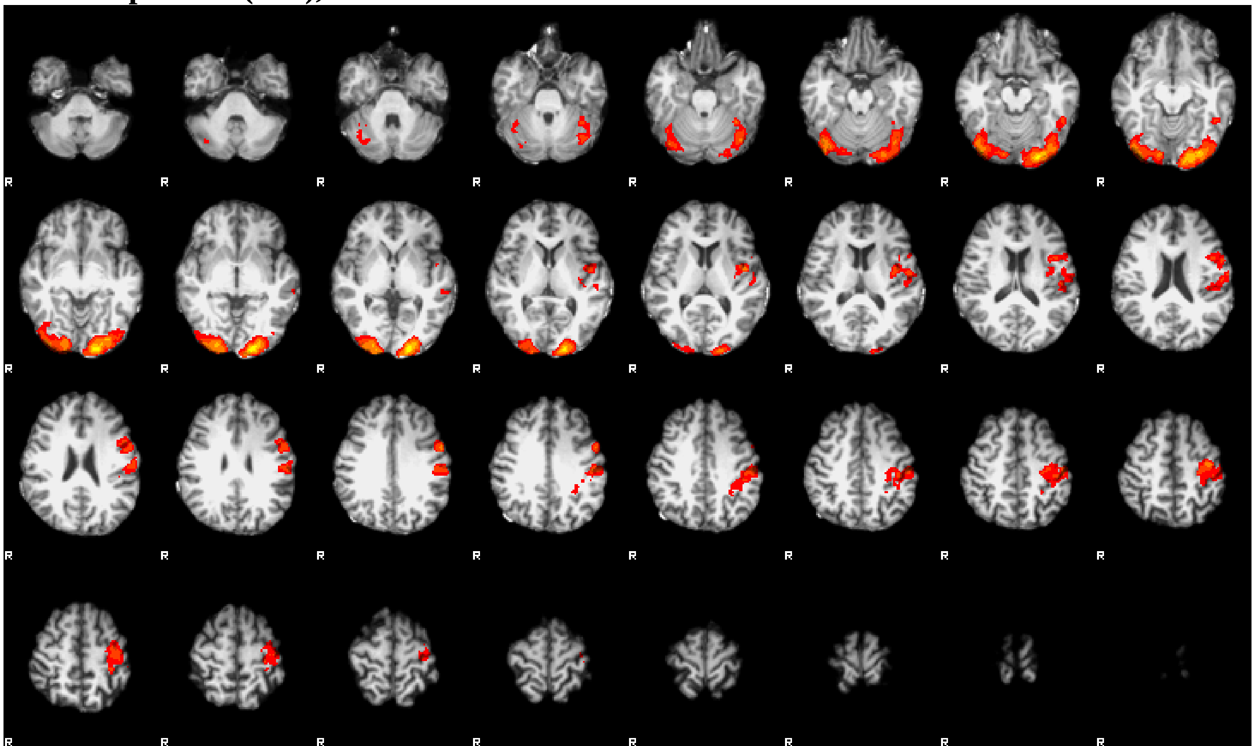
1.6	3.64	6	34	30	1. 67% Paracingulate Gyrus, 20% Cingulate Gyrus, anterior division 2. Right Cerebrum.Limbic Lobe.Cingulate Gyrus.Gray Matter.**BA32**
1.5	3.62	-8	28	22	1. 50% Cingulate Gyrus, anterior division, 8% Paracingulate Gyrus 2. Left Cerebrum.Limbic Lobe.Anterior Cingulate.Gray Matter.**BA32**
1.4	3.62	2	24	30	1. 71% Cingulate Gyrus, anterior division, 12% Paracingulate Gyrus 2. Inter-Hemispheric.
1.3	3.51	12	34	22	1. 31% Cingulate Gyrus, anterior division, 29% Paracingulate Gyrus 2. Right Cerebrum.Limbic Lobe.Anterior Cingulate.White Matter.
1.2	3.5	12	24	26	1. 32% Cingulate Gyrus, anterior division, 5% Paracingulate Gyrus 2. Right Cerebrum.Limbic Lobe.Cingulate Gyrus.Gray Matter.**BA32**
1.1	3.47	10	26	32	1. 41% Paracingulate Gyrus, 24% Cingulate Gyrus, anterior division 2. Right Cerebrum.Frontal Lobe.Cingulate Gyrus.Gray Matter.**BA32**

In English speakers, significant activations formed five clusters. The first cluster (5.6 ~ 5.1) is located in the right hemisphere that covers the Lateral Occipital Cortex, the Occipital Fusiform Gyrus, the Temporal Occipital Fusiform Cortex, and the Occipital Pole including BA 19 and 37. The second cluster (4.6 ~ 4.1) is located in the left hemisphere that covers the Lateral Occipital Cortex, the Temporal Occipital Fusiform Cortex, and the Occipital Fusiform Gyrus. The third cluster (3.6 ~ 3.1) is located in the left hemisphere that covers the IFG, the Temporal Pole, the Frontal Orbital Cortex, and the Frontal Operculum Cortex including BA 38 and 47. The forth cluster (2.6 ~ 2.1) is located mainly in the left hemisphere that covers the Frontal Pole, and the SFG including BA 6 and 9. The fifth cluster (1.6 ~ 1.1) is located in both right and left hemisphere that covers the anterior division of the Cingulate Gyrus and the Paracingulate Gyrus including BA 32. The English participants required activations in the DMPFC, the VMPFC, the left IFG, the left Frontal Pole, the left SFG, and the left Temporal Pole to differentiate abstract stimuli from concrete stimuli.

As for the group comparisons, there are no significant activations that form clusters in the contrasts of Chinese speakers vs. English speakers and English speakers vs. Chinese speakers. It is implied that there were no significant differences between the Chinese and English participants in using brain areas to differentiate concrete stimuli from abstract stimuli.

fMRI Data: Interpreting Different Types of Stimuli

Chinese speakers (n=9), Z: 2.3~6.5

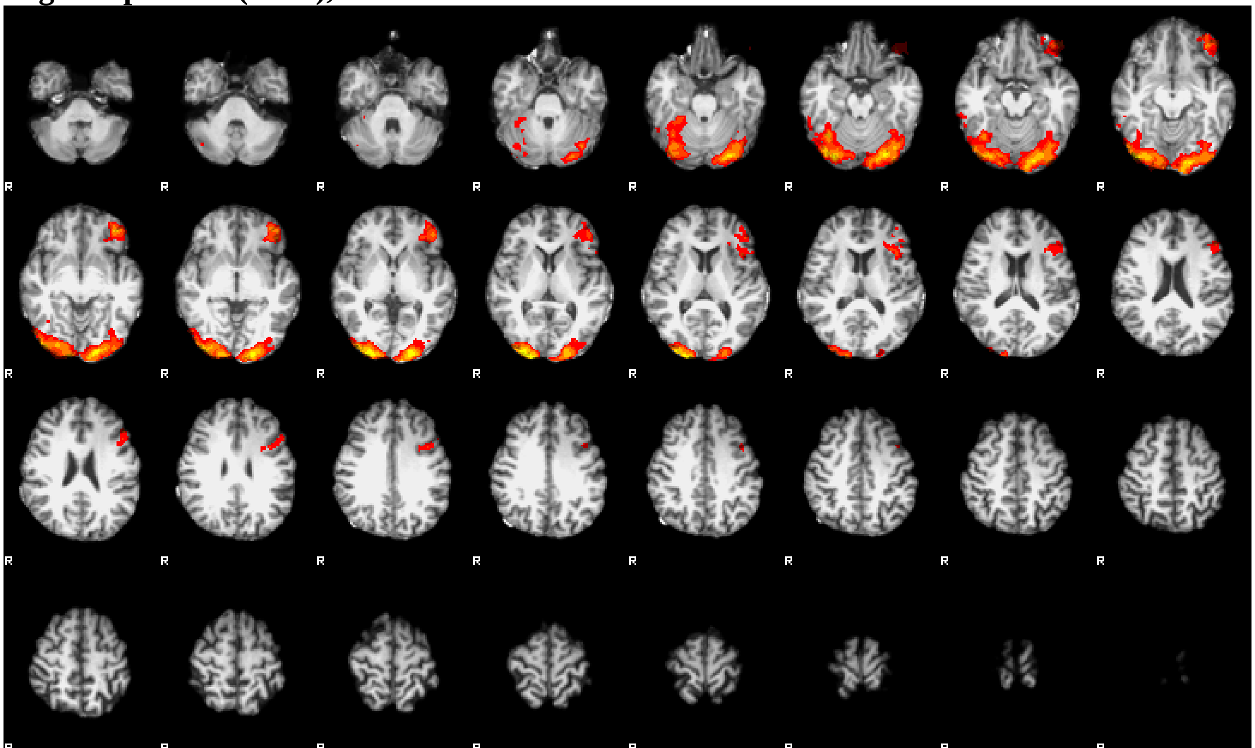


Cluster Index	Z	**x**	**y**	**z**	**Brain Areas (Coordinate Space: MNI_152)**
3.6	4.6	-40	-12	52	1. 58% Precentral Gyrus, 2% Postcentral Gyrus, 2% Middle Frontal Gyrus. 2. Left Cerebrum, Frontal Lobe, Precentral Gyrus, Gray matter, **BA4**.
3.5	4.42	-56	6	32	1. 56% Precentral Gyrus, 8% Inferior Frontal Gyrus, Pars Opercularis, 3% Middle Frontal Gyrus. 2. Left Cerebrum, Frontal Lobe, Precentral Gyrus, Gray Matter, **BA6**.
3.4	4.33	-46	-4	8	1. 76% Central Opercular Cortex, 1% Planum Polare. 2. Left Cerebrum, Sub-lobar, Insula, White Matter.
3.3	4.24	-58	-18	30	1. 59% Postcentral Gyrus, 11% Supramarginal Gyrus, Anterior Division. 2. Left Cerebrum, Parietal Lobe, Postcentral Gyrus, White Matter.
3.2	4.08	-50	-22	38	1. 43% Postcentral Gyrus, 12% Supramarginal Gyrus, Anterior Division. 2. Left Cerebrum, Parietal Lobe, Postcentral Gyrus, White Matter.
3.1	4.01	-54	-20	46	1. 60% Postcentral Gyrus, 5% Supramarginal Gyrus, Anterior Division, 1% Precentral Gyrus. 2. Left Cerebrum, Parietal Lobe, Postcentral Gyrus, Gray Matter, **BA2**.
2.6	6.4	-18	-98	2	1. 58% Occipital Pole, 2% Lateral Occipital Cortex, Inferior Division. 2. Left Cerebrum, Occipital Lobe, Cuneus, Gray Matter, **BA17**.
2.5	6.32	-18	-96	-2	1. 45% Occipital Pole, 3% Lateral Occipital Cortex, Inferior Division, 1% Occipital Fusiform Gyrus. 2. Left Cerebrum, Occipital Lobe, lingual Gyrus, White Matter.
2.4	6.25	-18	-98	-6	1. 51% Occipital Pole, 4% Lateral Occipital Cortex, Inferior Division. 2. Left Cerebrum, Occipital Lobe, Inferior Occipital Gyrus, Gray Matter, **BA17**.
2.3	6.17	-24	-90	-16	1. 28% Occipital Fusiform Gyrus, 21% Occipital Pole, 14% Lateral

					Occipital Cortex, Inferior Division, 1% Lingual Gyrus. 2. Left Cerebrum, Occipital Lobe, Fusiform Gyrus, Gray Matter, **BA18.**
2.2	5.8	-30	-86	-14	1. 27% Occipital Fusiform Gyrus, 20% Lateral Occipital Cortex, Inferior Division, 5% Occipital Pole. 2. Left Cerebellum, Posterior Lobe, Declive, Gray Matter.
2.1	4.46	-40	-80	-16	1. 51% Lateral Occipital Cortex, Inferior Division, 22% Occipital Fusiform Gyrus 2. Left Cerebrum, Posterior Lobe, Declive, Gray Matter.
1.6	5.19	24	-94	-2	1. 44% Occipital Pole, 5% Lateral Occipital Cortex, Inferior Division. 2. Right Cerebrum, Occipital Lobe, Lingual Gyrus, White Matter.
1.5	4.98	20	-98	-2	1. 53% Occipital Pole, 1% Lateral Occipital Cortex, Inferior Division. 2. Right Cerebrum, Occipital Lobe, Lingual Gyrus, White Matter.
1.4	4.96	42	-84	-14	1. 67% Lateral Occipital Cortex, Inferior Division, 3% Occipital Fusiform Gyrus, 1% Occipital Pole. 2. Right Cerebrum, Occipital Lobe, Fusiform Gyrus.
1.3	4.82	42	-74	-22	1. 9% Lateral Occipital Cortex, Inferior Division, 3% Occipital Fusiform Gyrus. 2. Right Cerebrum, Posterior Lobe, Declive, Gray Matter.
1.2	4.77	20	-90	-8	1. 28% Occipital Fusiform Gyrus, 22% Occipital Pole, 6% Lateral Occipital Cortex, Inferior Division, 5% Lingual Gyrus. 2. Right Cerebrum, Occipital Lobe, Lingual Gyrus, White Matter.
1.1	4.68	30	-98	-2	1. 69% Occipital Pole, 1% Lateral Occipital Cortex, Inferior Division. 2. Right Cerebrum, Occipital Lobe, Lingual Gyrus, Gray Matter, **BA18**.

In Chinese speakers, significant activations formed three major clusters. The first cluster (3.6 ~ 3.1) is located in the left hemisphere that covers the Postcentral Gyrus, the anterior division of the Supramarginal Gyrus (SMG), the Central Opercular Cortex, and the Precentral Gyrus including Brodmann area (BA) 2, 4, and 6. The second cluster (2.6 ~ 2.1) is located in the left hemisphere that covers the Occipital Fusiform Gyrus, the inferior division of the Lateral Occipital Cortex, the Occipital Pole including BA 17 and 18. The third cluster (1.6 ~ 1.1) is located in the right hemisphere that covers the Occipital Pole, the Occipital Fusiform Gyrus, and the inferior division of the Lateral Occipital Cortex including BA 18. It implies that these brain areas are critical for Chinese speakers to interprete icons, pictures, single English words, and single Chinese characters in the concrete vs. abstract judgment task. Besides areas that handle vision and motor processes, Chinese speakers reply on the SMG in the left hemisphere that plays a critical role in complex information integration and knowledge retrieval for this task.

English speakers (n=10), Z: 2.3~6.5



Cluster Index	Z	x	y	z	Brain Areas (Coordinate Space: MNI_152)
2.6	6.54	30	-96	2	1. 69% Occipital Pole, 4% Lateral Occipital Cortex, Inferior Division. 2. Right Cerebrum, Occipital Lobe, Cuneus, White Matter.
2.5	6.48	-16	-96	-8	1. 61% Occipital Pole, 5% Lateral Occipital Cortex, Inferior Division, 2% Occipital Fusiform Gyrus. 2. Left Cerebrum, Occipital Lobe, Inferior Occipital Gyrus, Gray Matter, **BA17**.
2.4	6.39	20	-100	6	1. 67% Occipital Pole. 2. Right Cerebrum, Occipital Lobe, Cuneus, White Matter.
2.3	6.34	-20	-98	0	1. 56% Occipital Pole, 3% Lateral Occipital Cortex, Inferior Division. 2. Left Cerebrum, Occipital Lobe, Lingual Gyrus, White Matter.
2.2	6.11	32	-84	-14	1. 31% Lateral Occipital Cortex, Inferior Division, 30% Occipital Fusiform Gyrus, 3% Occipital Pole. 2. Right Cerebrum, Occipital Lobe, Fusiform Gyrus, White Matter.
2.1	6.06	-28	-84	-22	1. 17% Occipital Fusiform Gyrus, 12% Lateral Occipital Cortex, Inferior Division, 1% Lingual Gyrus. 2. Left Cerebellum, Posterior Lobe, Declive, Gray Matter.
1.6	5.06	-40	46	-8	1. 55% Frontal Pole. 2. Left Cerebrum, Frontal Lobe, Sub-Gyral, White Matter.
1.5	4.15	-46	42	0	1. 80% Frontal Pole, 3% Inferior Frontal Gyrus, Pars Triangularis. 2. Left Cerebrum, Frontal Lobe, Inferior Frontal Gyrus, White Matter.
1.4	4.11	-44	38	-2	1. 30% Frontal Pole, 8% Inferior Frontal Gyrus, Pars Triangularis, 6% Frontal Orbital Cortex. 2. Left Cerebrum, Frontal Lobe, Inferior Frontal Gyrus, White Matter.
1.3	4.03	-50	46	-14	1. 21% Frontal Pole. 2. Left Cerebrum, Frontal Lobe, Middle Frontal Gyrus, White Matter.
1.2	3.71	-42	20	10	1. 17% Inferior Frontal Gyrus, Pars Triangularis, 13% Inferior Frontal Gyrus, Pars Opercularis, 10% Frontal Operculum Cortex.

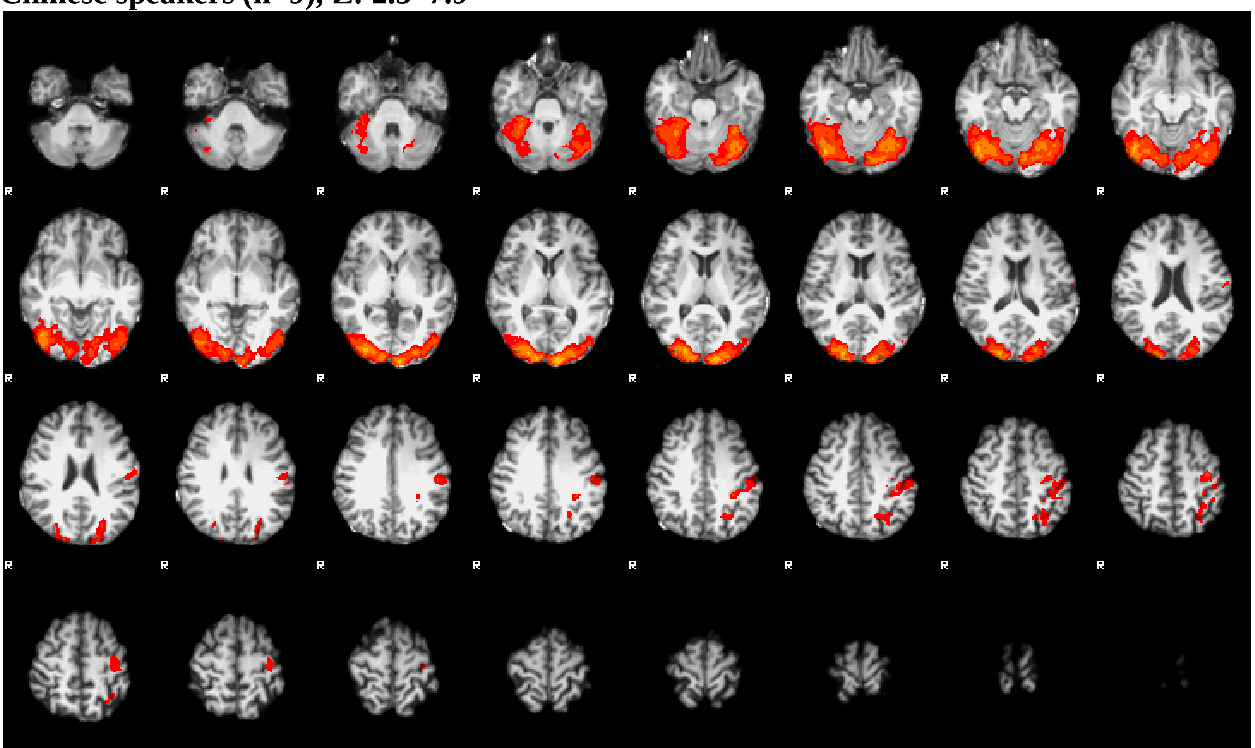
					2. Left Cerebrum, Frontal Lobe, Inferior Frontal Gyrus, Gray Matter, **BA45**.
1.1	3.63	-34	26	12	1. 11% Frontal Operculum Cortex, 5% Inferior Frontal Gyrus, Pars Triangularis. 2. Left Cerebrum, Frontal Lobe, Sub-Gyral, White Matter.

In English speakers, significant activations formed two major clusters. The first cluster (2.6 ~ 2.1) is located in both left and right hemispheres that covers the Occipital Pole, the inferior division of the Lateral Occipital Cortex, and the Occipital Fusiform Gyrus including BA 17. The second cluster (1.6 ~ 1.1) is located in the left hemisphere that covers the Frontal Pole, the Frontal Operculum Cortex, and the Inferior Frontal Gyrus (IFG) including BA 45. It implied that besides areas that handle vision processes, English speakers replied on the IFG in the left hemisphere that was related to phonological, working memory, and syntactic processes that might affect the efficiency of semantic processing.

As for the group comparisons, there were no significant activations that formed clusters in the contrasts of Chinese speakers vs. English speakers and English speakers vs. Chinese speakers. It is implied that English and Chinese speakers were using the same brain regions to process these four types of stimuli.

fMRI Data: Interpreting Icons

Chinese speakers (n=9), Z: 2.3~7.9

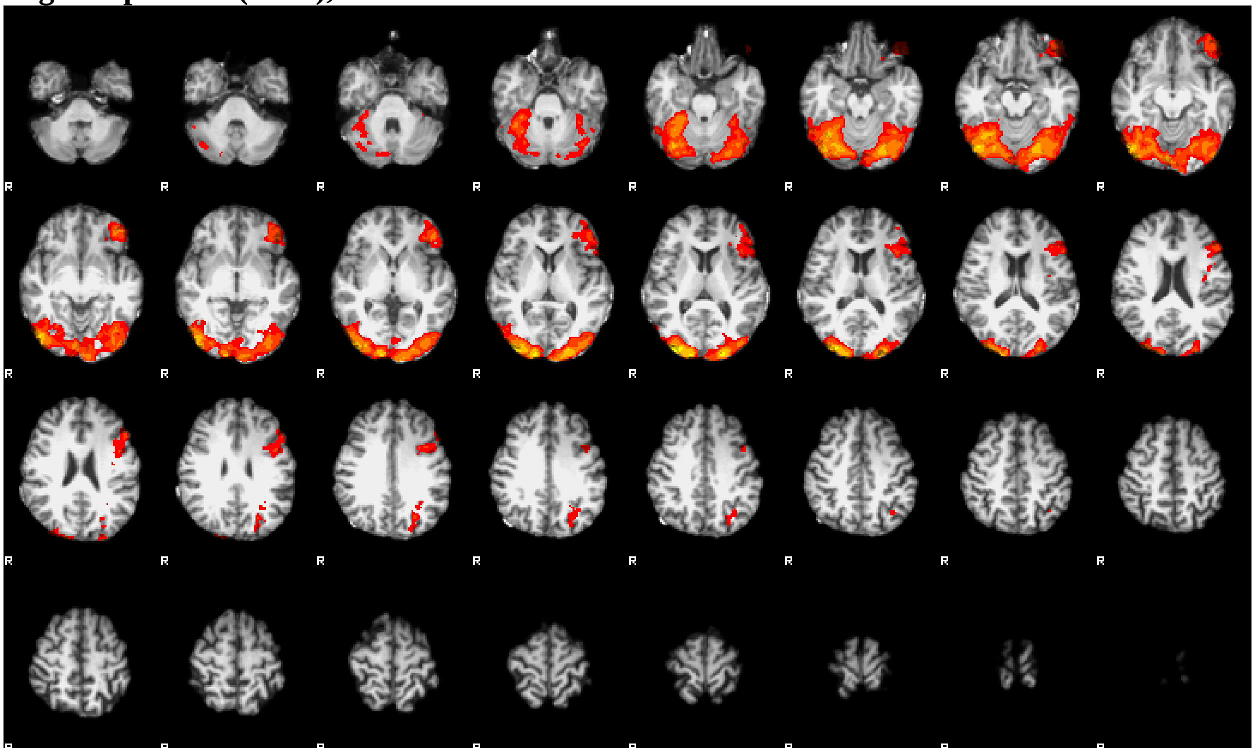


Cluster Index	Z	x	y	z	Brain Areas (Coordinate Space: MNI_152)
2.6	6.65	-12	-100	4	1. 50% Occipital Pole, 1% Lateral Occipital Cortex, superior Division 2. Left Cerebrum.Occipital Lobe.Cuneus.Gray Matter.
2.5	6.48	22	-92	12	1. 29% Occipital Pole, 7% Lateral Occipital Cortex, superior Division, 1% Cuneal Cortex 2. Right Cerebrum.Occipital Lobe.Cuneus.White Matter.

2.4	6.3	42	-74	-20	1. 27% Lateral Occipital Cortex, Inferior Division, 6% Occipital Fusiform Gyrus 2. Right Cerebellum.Posterior Lobe.Declive.Gray Matter.
2.3	6.25	14	-96	6	1. 64% Occipital Pole, 2% Lingual Gyrus, 2% Intracalcarine Cortex, 1% Supracalcarine Cortex 2. Right Cerebrum.Occipital Lobe.Cuneus.Gray Matter.**BA17**
2.2	6.12	44	-68	-10	1. 52% Lateral Occipital Cortex, Inferior Division, 9% Occipital Fusiform Gyrus, 2% Temporal Occipital Fusiform Cortex, 2% Inferior Temporal Gyrus, temporooccipital part 2. Right Cerebrum.Occipital Lobe.Sub-Gyral.White Matter.
2.1	6.08	24	-90	6	1. 15% Occipital Pole, 8% Lateral Occipital Cortex, Inferior Division, 5% Lateral Occipital Cortex, superior Division, 1% Intracalcarine Cortex 2. Right Cerebrum.Occipital Lobe.Lingual Gyrus.White Matter.
1.6	4.09	-40	-14	52	1. 57% Precentral Gyrus, 7% Postcentral Gyrus 2. Left Cerebrum.Parietal Lobe.Precentral Gyrus.
1.5	4.01	-32	-38	38	1. 15% Postcentral Gyrus, 11% Supramarginal Gyrus, Anterior Division, 6% Superior Parietal Lobule, 4% Supramarginal Gyrus, Posterior Division 2. Left Cerebrum.Parietal Lobe.Sub-Gyral.White Matter.
1.4	3.92	-58	-18	36	1. 71% Postcentral Gyrus, 9% Supramarginal Gyrus, Anterior Division 2. Left Cerebrum.Parietal Lobe.Postcentral Gyrus.Gray Matter.**BA3**
1.3	3.73	-52	-20	34	1. 45% Postcentral Gyrus, 9% Supramarginal Gyrus, Anterior Division 2. Left Cerebrum.Parietal Lobe.Postcentral Gyrus.White Matter.
1.2	3.48	-44	-26	44	1. 51% Postcentral Gyrus, 5% Supramarginal Gyrus, Anterior Division 2. Left Cerebrum.Parietal Lobe.Inferior Parietal Lobule.Gray Matter.**BA40**
1.1	3.38	-18	-62	44	1. 16% Lateral Occipital Cortex, superior Division, 9% Precuneous Cortex, 1% Angular Gyrus, 1% Superior Parietal Lobule 2. Left Cerebrum.Parietal Lobe.PreCuneus.White Matter.

In Chinese speakers, significant activations formed two clusters. The first cluster (2.6 ~ 2.1) is located mainly in the right hemisphere that covers the Occipital Pole, the Lateral Occipital Cortex, and the Occipital Fusiform Gyrus including BA 17. The second cluster (1.6 ~ 1.1) is located in the left hemisphere the covers the Postcentral Gyrus, the Precentral Gyrus, the superior division of the Lateral Occipital Cortex, and the anterior division of the SMG including BA 2 and 40. It implied that icons demanded more resources in the Fusiform Gyrus (critical for retrieving knowledge about the visual attributes of concrete objects), and the left SMG (critical for complex information integration and knowledge retrieval) for Chinese speakers to understand their meanings.

English speakers (n=10), Z: 2.3~7.9



Cluster Index	Z	x	y	z	Brain Areas (Coordinate Space: MNI_152)
2.6	7.97	34	-92	8	1. 58% Occipital Pole, 10% Lateral Occipital Cortex, superior Division, 6% Lateral Occipital Cortex, Inferior Division 2. Right Cerebrum.Occipital Lobe.Middle Occipital Gyrus.Gray Matter.**BA18**
2.5	7.33	18	-98	6	1. 53% Occipital Pole 2. Right Cerebrum.Occipital Lobe.Cuneus.Gray Matter.**BA17**
2.4	7.22	48	-76	-10	1. 78% Lateral Occipital Cortex, Inferior Division, 3% Occipital Fusiform Gyrus 2. Right Cerebrum.Occipital Lobe.Middle Occipital Gyrus.White Matter.
2.3	7.1	-20	-98	8	1. 37% Occipital Pole, 1% Lateral Occipital Cortex, Inferior Division, 1% Lateral Occipital Cortex, superior Division 2. Left Cerebrum.Occipital Lobe.Cuneus.White Matter.
2.2	7.05	14	-98	2	1. 73% Occipital Pole 2. Right Cerebrum.Occipital Lobe.Cuneus.
2.1	6.95	46	-74	-16	1. 61% Lateral Occipital Cortex, Inferior Division, 13% Occipital Fusiform Gyrus 2. Right Cerebellum.Posterior Lobe.Declive.Gray Matter.
1.6	5.24	-38	44	-8	1. 41% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
1.5	5.07	-48	42	0	1. 87% Frontal Pole, 3% Inferior Frontal Gyrus, pars triangularis 2. Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
1.4	4.9	-50	44	-14	1. 37% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
1.3	4.37	-52	26	22	1. 42% Inferior Frontal Gyrus, pars triangularis, 21% Middle Frontal Gyrus, 10% Inferior Frontal Gyrus, pars opercularis 2. Left Cerebrum.Frontal Lobe.Middle Frontal Gyrus.Gray Matter.**BA46**

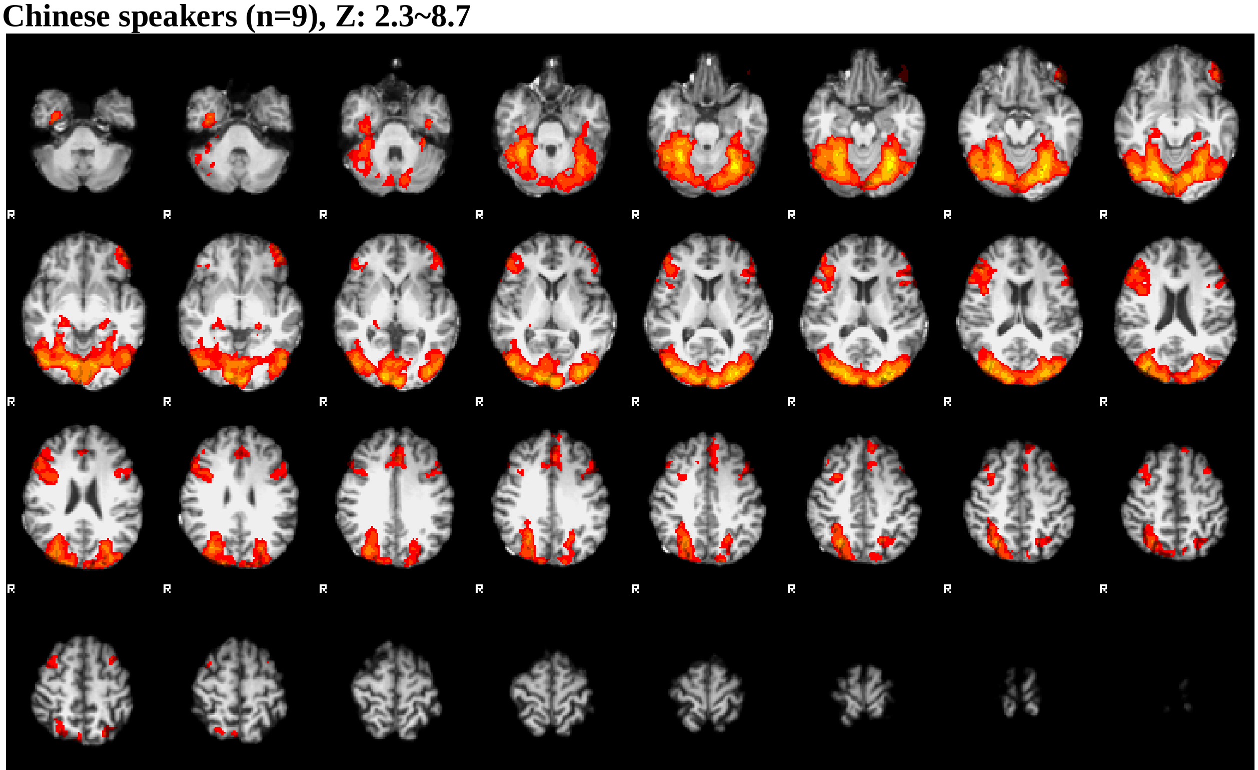
1.2	4.24	-50	30	24	1. 45% Middle Frontal Gyrus, 19% Inferior Frontal Gyrus, pars triangularis, 3% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
1.1	4.04	-42	20	12	1. 13% Inferior Frontal Gyrus, pars triangularis, 8% Inferior Frontal Gyrus, pars opercularis, 3% Frontal Operculum Cortex 2. Left Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.

In English speakers, significant activations formed two clusters. The first cluster (2.6 ~ 2.1) is located mainly in the right hemisphere that covers the Lateral Occipital Cortex, the Occipital Pole, and the Occipital Fusiform Gyrus including BA 17 and 18. The second cluster (1.6 ~ 1.1) is located in the left hemisphere that covers the IFG, the Frontal Pole, and the MFG including BA 46. Icon interpretation demanded resources of the left IFG in English speakers. It implied that English speakers used phonological processing to interpret icons.

As for the group comparisons, there are no significant activations that form clusters in the contrasts of Chinese speakers vs. English speakers and English speakers vs. Chinese speakers. It implied that Chinese and English speakers were not significantly different in using their brains to interpret icons; thus the left SMG and IFG might both be needed to interpret icons besides regions that are critical for object recognition.

fMRI Data: Icons vs. Chinese Characters

Chinese speakers (n=9), Z: 2.3~8.7



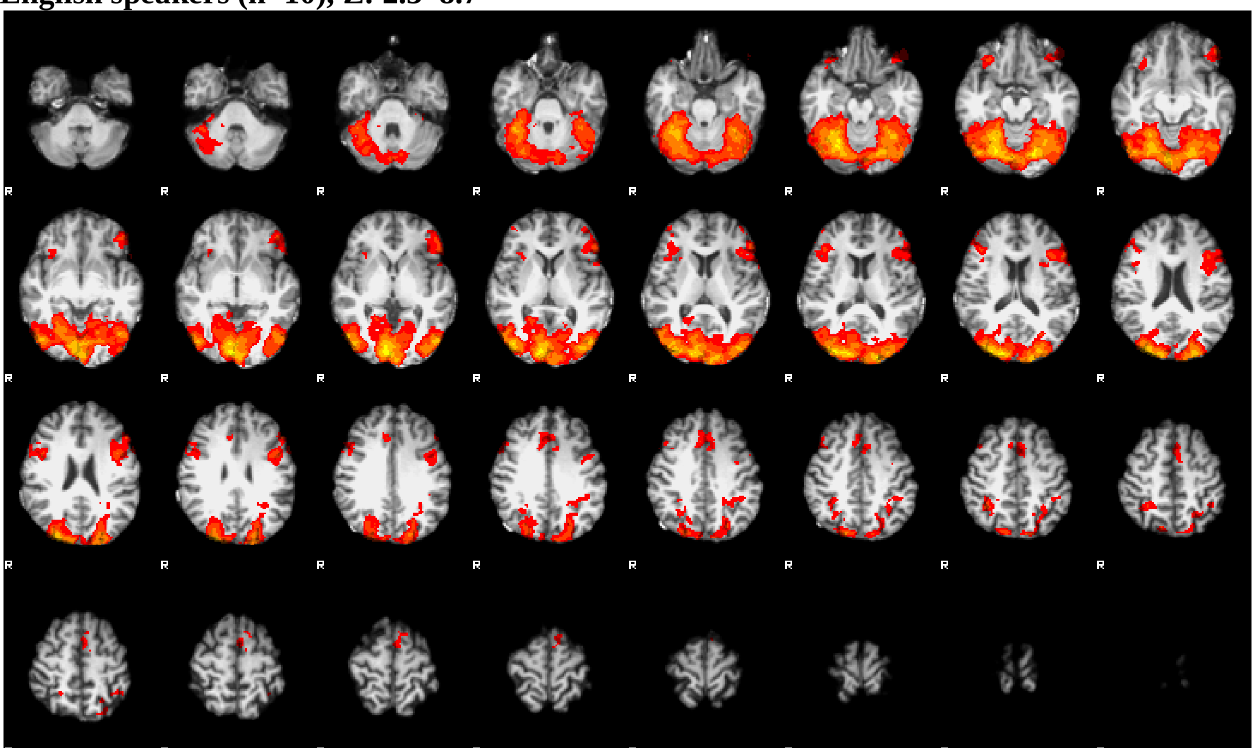
Cluster Index	Z	x	y	z	Brain Areas (Coordinate Space: MNI_152)
4.6	8.77	24	-72	-14	1. 66% Occipital Fusiform Gyrus, 12% Lingual Gyrus 2. Right Cerebellum.Posterior Lobe.Declive.Gray Matter.
4.5	8.53	12	-78	-10	1. 49% Lingual Gyrus, 22% Occipital Fusiform Gyrus, 1% Lateral Occipital Cortex, Inferior Division 2. Right Cerebellum.Posterior Lobe.Declive.Gray Matter.

4.4	8.33	22	-90	12	1. 20% Occipital Pole, 8% Lateral Occipital Cortex, superior Division, 1% Cuneal Cortex 2. Right Cerebrum.Occipital Lobe.Cuneus.White Matter.
4.3	8.32	-30	-64	-20	1. 16% Temporal Occipital Fusiform Cortex, 11% Occipital Fusiform Gyrus 2. Left Cerebellum.Posterior Lobe.Declive.Gray Matter.
4.2	8.03	30	-56	-22	1. 2% Temporal Occipital Fusiform Cortex 2. Right Cerebellum.Anterior Lobe.Culmen.Gray Matter.
4.1	7.94	24	-64	-14	1. 40% Occipital Fusiform Gyrus, 17% Lingual Gyrus, 14% Temporal Occipital Fusiform Cortex 2. Right Cerebellum.Posterior Lobe.Declive.Gray Matter.
3.6	5.62	46	32	18	1. 30% Inferior Frontal Gyrus, pars triangularis, 27% Middle Frontal Gyrus, 8% Frontal Pole, 1% Inferior Frontal Gyrus, pars opercularis 2. Right Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
3.5	5.49	44	32	14	1. 32% Inferior Frontal Gyrus, pars triangularis, 10% Middle Frontal Gyrus, 8% Frontal Pole 2. Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
3.4	4.93	42	10	18	1. 11% Inferior Frontal Gyrus, pars opercularis, 5% Precentral Gyrus 2. Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
3.3	4.84	52	24	24	1. 21% Inferior Frontal Gyrus, pars opercularis, 15% Inferior Frontal Gyrus, pars triangularis, 15% Middle Frontal Gyrus, 2% Precentral Gyrus 2. Right Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
3.2	4.83	42	24	18	1. 10% Inferior Frontal Gyrus, pars opercularis, 10% Inferior Frontal Gyrus, pars triangularis, 6% Middle Frontal Gyrus 2. Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
3.1	4.79	48	38	6	1. 46% Frontal Pole, 15% Inferior Frontal Gyrus, pars triangularis, 1% Middle Frontal Gyrus 2. Right Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
2.6	4.49	-48	38	-14	1. 62% Frontal Pole, 27% Frontal Orbital Cortex, 1% Inferior Frontal Gyrus, pars triangularis 2. Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
2.5	4.33	-50	48	-10	1. 24% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
2.4	4.21	-48	50	-6	1. 47% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
2.3	4.02	-42	56	-6	1. 76% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.Gray Matter.**BA10**
2.2	3.98	-58	20	18	1. 39% Inferior Frontal Gyrus, pars opercularis, 8% Inferior Frontal Gyrus, pars triangularis 2. Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
2.1	3.94	-40	62	-2	1. 31% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Middle Frontal Gyrus.Gray Matter.**BA10**
1.6	4.47	-2	30	32	1. 64% Paracingulate Gyrus, 21% Cingulate Gyrus, Anterior Division 2. Left Cerebrum.Frontal Lobe.Cingulate Gyrus.
1.5	4.16	-4	44	36	1. 57% Superior Frontal Gyrus, 15% Paracingulate Gyrus 2. Left Cerebrum.Frontal Lobe.Medial Frontal Gyrus.Gray Matter.**BA8**
1.4	3.96	-8	44	44	1. 24% Frontal Pole, 10% Superior Frontal Gyrus 2. Left Cerebrum.Frontal Lobe.Superior Frontal Gyrus.White Matter.
1.3	3.4	2	38	26	1. 66% Paracingulate Gyrus, 23% Cingulate Gyrus, Anterior Division 2. Inter-Hemispheric.

1.2	3.37	-10	28	42	1. 5% Superior Frontal Gyrus, 4% Paracingulate Gyrus 2. Left Cerebrum.Frontal Lobe.Superior Frontal Gyrus.White Matter.
1.1	3.23	-10	22	34	1. 46% Paracingulate Gyrus, 12% Cingulate Gyrus, Anterior Division 2. Left Cerebrum.Frontal Lobe.Cingulate Gyrus.White Matter.

In Chinese speakers, significant activations formed four clusters. The first cluster (4.6 ~ 4.1) is located in the right hemisphere that covers the Occipital Fusiform Gyrus, the Temporal Occipital Fusiform Cortex, the Lingual Gyrus, and the Occipital Pole. The second cluster (3.6 ~ 3.1) is located in the right hemisphere that covers the Frontal Pole, the IFG, and the MFG. The third cluster (2.6 ~ 2.1) is located in the left hemisphere that covers the Frontal Pole, the IFG, and the Frontal Orbital Cortex including BA 10. The forth cluster (1.6 ~ 1.1) is located in the left hemisphere that covers the Paracingulate Gyrus, the anterior division of the Cingulate Gyrus, the SFG, and the Frontal Pole including BA 8. The Chinese participants required bilateral activations in the IFG and the Frontal Pole, and regions close to the left DMPFC and VMPFC to differentiate icons from Chinese characters.

English speakers (n=10), Z: 2.3~8.7



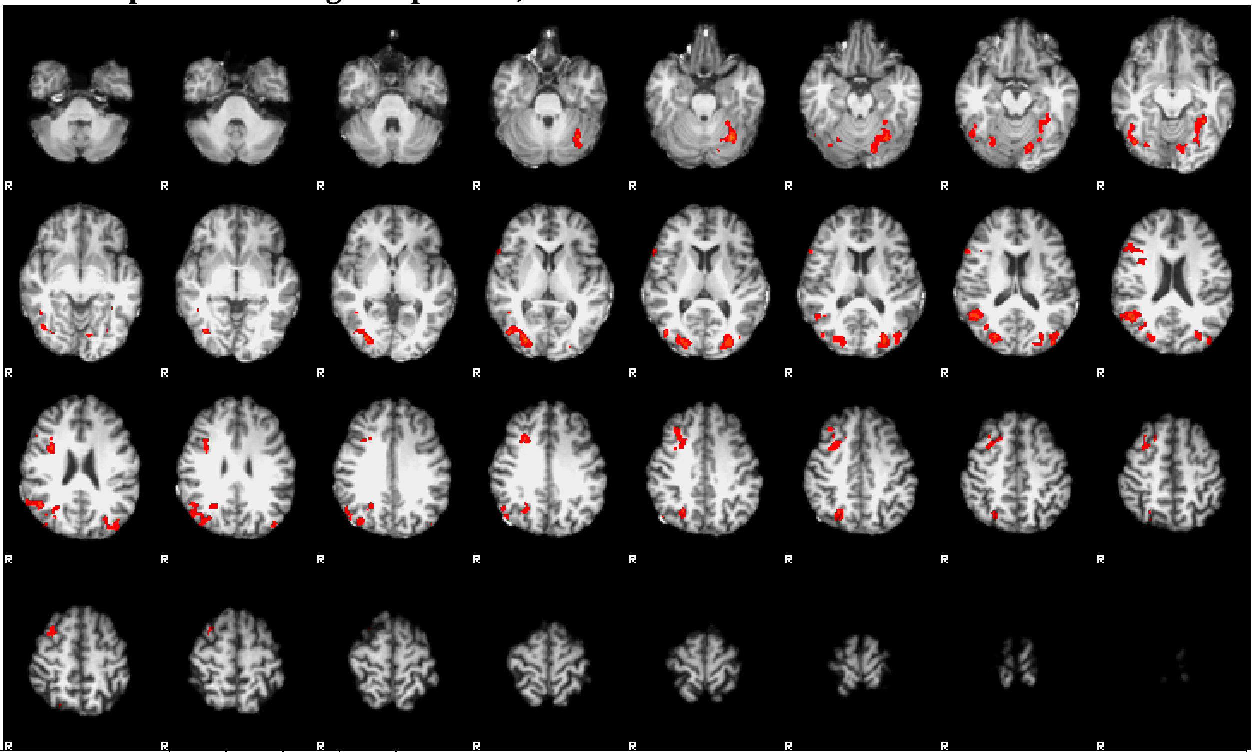
Cluster Index	Z	x	y	z	Brain Areas (Coordinate Space: MNI_152)
4.6	8.43	10	-90	2	1. 38% Occipital Pole, 23% Intracalcarine Cortex, 8% Lingual Gyrus, 1% Supracalcarine Cortex 2. Right Cerebrum.Occipital Lobe.Lingual Gyrus.White Matter.
4.5	8.3	22	-76	-18	1. 23% Occipital Fusiform Gyrus, 6% Lingual Gyrus 2. Right Cerebellum.Posterior Lobe.Declive.Gray Matter.
4.4	8.27	-20	-76	-16	1. 42% Occipital Fusiform Gyrus, 14% Lingual Gyrus, 1% Lateral Occipital Cortex, Inferior Division 2. Left Cerebellum.Posterior Lobe.Declive.Gray Matter.
4.3	8.18	28	-68	-18	1. 30% Occipital Fusiform Gyrus, 3% Temporal Occipital Fusiform Cortex

					2. Right Cerebellum.Posterior Lobe.Declive.Gray Matter.
4.2	8.11	16	-92	14	1. 29% Occipital Pole, 3% Supracalcarine Cortex, 3% Lateral Occipital Cortex, superior Division, 2% Cuneal Cortex 2. Right Cerebrum.Occipital Lobe.Cuneus.White Matter.
4.1	7.95	28	-60	-18	1. 28% Temporal Occipital Fusiform Cortex, 4% Occipital Fusiform Gyrus 2. Right Cerebellum.Posterior Lobe.Declive.Gray Matter.
3.6	5.12	-42	10	26	1. 32% Inferior Frontal Gyrus, pars opercularis, 16% Precentral Gyrus, 8% Middle Frontal Gyrus 2. Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
3.5	4.54	-54	34	8	1. 43% Inferior Frontal Gyrus, pars triangularis, 18% Frontal Pole, 3% Middle Frontal Gyrus 2. Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
3.4	4.26	-54	30	2	1. 62% Inferior Frontal Gyrus, pars triangularis, 7% Frontal Pole, 5% Frontal Orbital Cortex, 1% Inferior Frontal Gyrus, pars opercularis 2. Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
3.3	4.18	-40	22	16	1. 8% Inferior Frontal Gyrus, pars opercularis, 7% Inferior Frontal Gyrus, pars triangularis, 1% Middle Frontal Gyrus 2. Left Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
3.2	4.16	-50	44	-10	1. 65% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
3.1	4.15	-52	40	0	1. 61% Frontal Pole, 9% Inferior Frontal Gyrus, pars triangularis, 3% Frontal Orbital Cortex 2. Left Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.Gray Matter.**BA45**
2.6	4.38	42	30	14	1. 22% Inferior Frontal Gyrus, pars triangularis, 8% Middle Frontal Gyrus, 3% Frontal Pole, 1% Inferior Frontal Gyrus, pars opercularis 2. Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
2.5	4.2	32	34	-16	1. 49% Frontal Pole, 41% Frontal Orbital Cortex 2. Right Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
2.4	3.9	46	6	24	1. 37% Precentral Gyrus, 23% Inferior Frontal Gyrus, pars opercularis 2. Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
2.3	3.87	44	10	24	1. 31% Inferior Frontal Gyrus, pars opercularis, 17% Precentral Gyrus, 1% Middle Frontal Gyrus 2. Right Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
2.2	3.48	34	28	-12	1. 39% Frontal Orbital Cortex, 2% Insular Cortex, 2% Frontal Pole 2. Right Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
2.1	3.37	34	28	-8	1. 50% Frontal Orbital Cortex, 4% Insular Cortex, 2% Frontal Pole 2. Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
1.6	3.83	-2	12	50	1. 58% Paracingulate Gyrus, 9% Superior Frontal Gyrus, 7% Juxtapositional Lobule Cortex (formerly Supplementary Motor Cortex), 1% Cingulate Gyrus, Anterior Division 2. Left Cerebrum.Frontal Lobe.Superior Frontal Gyrus.Gray Matter.**BA6**
1.5	3.8	6	24	38	1. 50% Paracingulate Gyrus, 27% Cingulate Gyrus, Anterior Division 2. Right Cerebrum.Limbic Lobe.Cingulate Gyrus.Gray Matter.**BA32**
1.4	3.68	8	28	32	1. 49% Paracingulate Gyrus, 29% Cingulate Gyrus, Anterior Division 2. Right Cerebrum.Frontal Lobe.Cingulate Gyrus.Gray Matter.**BA32**
1.3	3.63	-4	4	58	1. 73% Juxtapositional Lobule Cortex (formerly Supplementary Motor Cortex), 7% Superior Frontal Gyrus, 2% Paracingulate Gyrus 2. Left Cerebrum.Frontal Lobe.Medial Frontal Gyrus.White Matter.
1.2	3.47	-8	18	42	1. 58% Paracingulate Gyrus, 4% Superior Frontal Gyrus, 2% Cingulate

					Gyrus, Anterior Division 2. Left Cerebrum.Limbic Lobe.Cingulate Gyrus.White Matter.
1.1	3.31	-6	18	50	1. 29% Paracingulate Gyrus, 25% Superior Frontal Gyrus 2. Left Cerebrum.Frontal Lobe.Superior Frontal Gyrus.White Matter.

In English speakers, significant activations formed four clusters. The first cluster (4.6 ~ 4.1) is located mainly in the right hemisphere that covers the Temporal Occipital Fusiform Gyrus, the Occipital Fusiform Gyrus, the Occipital Pole, the Lingual Gyrus, and the Intracalcarine Cortex. The second cluster (3.6 ~ 3.1) is located in the left hemisphere that covers the Frontal Pole, the IFG, the MFG, the Precentral Gyrus and the Frontal Orbital Cortex including BA 45. The third cluster (2.6 ~ 2.1) is located in the right hemisphere that covers the Frontal Orbital Cortex, the Frontal Pole, the IFG, and the Precentral Gyrus. The forth cluster (1.6 ~ 1.1) is located in both right and left hemisphere that covers the Paracingulate Gyrus, the SFG, the anterior division of the Cingulate Gyrus, and the SMC including BA 6 and 32. Similar to Chinese speakers, English speakers required bilateral activations of the Frontal Pole and the IFG, and regions close to the DMPFC and the VMPFC in both hemispheres to differentiate icons from Chinese characters.

Chinese speakers vs. English speakers, Z: 2.3~8.7



Cluster Index	Z	x	y	z	Brain Areas (Coordinate Space: MNI_152)
4.6	5.16	28	-82	4	1. 12% Lateral Occipital Cortex, Inferior Division, 4% Lateral Occipital Cortex, superior Division, 1% Occipital Pole, 1% Occipital Fusiform Gyrus 2. Right Cerebrum.Occipital Lobe.Sub-Gyral.White Matter.
4.5	4.54	46	-74	6	1. 59% Lateral Occipital Cortex, Inferior Division, 1% Lateral Occipital Cortex, superior Division 2. Right Cerebrum.Occipital Lobe.Middle Occipital Gyrus.White Matter.

4.4	4.2	48	-56	22	1. 36% Angular Gyrus, 7% Lateral Occipital Cortex, superior Division, 3% Middle Temporal Gyrus, temporooccipital part 2. Right Cerebrum.Temporal Lobe.Superior Temporal Gyrus.Gray Matter.**BA39**
4.3	4.04	52	-52	18	1. 54% Angular Gyrus, 14% Middle Temporal Gyrus, temporoOccipital part, 4% Supramarginal Gyrus, Posterior Division 2. Right Cerebrum.Temporal Lobe.Superior Temporal Gyrus.White Matter.
4.2	3.93	36	-72	-2	1. 6% Lateral Occipital Cortex, Inferior Division, 4% Occipital Fusiform Gyrus 2. Right Cerebrum.Occipital Lobe.Sub-Gyral.White Matter.
4.1	3.91	26	-64	40	1. 54% Lateral Occipital Cortex, superior Division, 2% Precuneous Cortex, 1% Angular Gyrus 2. Right Cerebrum.Parietal Lobe.PreCuneus.Gray Matter.**BA7**
3.6	4	36	10	24	1. 15% Inferior Frontal Gyrus, pars opercularis, 6% Precentral Gyrus, 2% Middle Frontal Gyrus 2. Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
3.5	3.75	28	22	36	1. 16% Middle Frontal Gyrus, 4% Superior Frontal Gyrus 2. Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
3.4	3.59	34	10	44	1. 22% Middle Frontal Gyrus, 1% Precentral Gyrus 2. Right Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
3.3	3.47	34	10	54	1. 25% Middle Frontal Gyrus, 5% Superior Frontal Gyrus, 3% Precentral Gyrus 2. Right Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
3.2	3.33	60	22	6	1. 12% Inferior Frontal Gyrus, pars triangularis, 11% Inferior Frontal Gyrus, pars opercularis 2. Right Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.Gray Matter.**BA45**
3.1	3.23	28	12	42	1. 13% Middle Frontal Gyrus, 3% Superior Frontal Gyrus, 1% Precentral Gyrus 2. Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
2.6	5.48	-30	-64	-24	1. No label found 2. Left Cerebellum.Anterior Lobe.Culmen.Gray Matter.
2.5	4.08	-14	-78	-18	1. 15% Occipital Fusiform Gyrus, 14% Lingual Gyrus 2. Left Cerebellum.Posterior Lobe.Declive.Gray Matter.
2.4	3.93	-36	-44	-12	1. 11% Temporal Occipital Fusiform Cortex, 10% Temporal Fusiform Cortex, Posterior Division, 1% Lingual Gyrus, 1% Parahippocampal Gyrus, Posterior Division 2. Left Cerebrum.Temporal Lobe.Fusiform Gyrus.White Matter.
2.3	3.57	-34	-72	-26	1. 1% Occipital Fusiform Gyrus 2. Left Cerebellum.Posterior Lobe.Uvula.Gray Matter.
2.2	3.47	-8	-76	-12	1. 54% Lingual Gyrus, 13% Occipital Fusiform Gyrus 2. Left Cerebellum.Posterior Lobe.Declive.Gray Matter.
2.1	3.35	-28	-54	-12	1. 50% Temporal Occipital Fusiform Cortex, 3% Lingual Gyrus, 1% Occipital Fusiform Gyrus, 1% Temporal Fusiform Cortex, Posterior Division, 1% Inferior Temporal Gyrus, temporoOccipital part 2. Left Cerebellum.Posterior Lobe.Declive.Gray Matter.
1.6	4.67	-28	-86	8	1. 24% Lateral Occipital Cortex, Inferior Division, 17% Lateral Occipital Cortex, superior Division, 5% Occipital Pole 2. Left Cerebrum.Occipital Lobe.Middle Occipital Gyrus.White Matter.
1.5	3.72	-42	-84	16	1. 58% Lateral Occipital Cortex, superior Division, 17% Lateral Occipital Cortex, Inferior Division, 2% Occipital Pole 2. Left Cerebrum.Occipital Lobe.Middle Occipital Gyrus.White Matter.

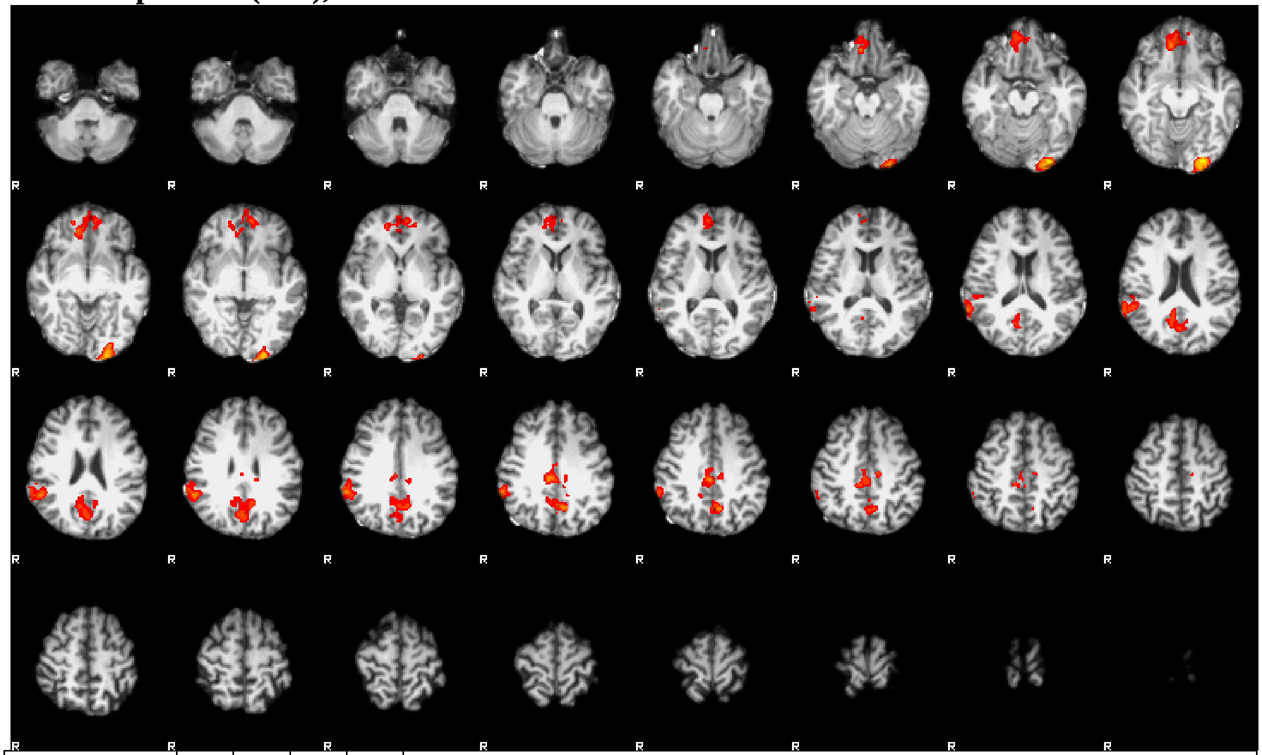
1.4	3.69	-40	-84	22	1. 73% Lateral Occipital Cortex, superior Division, 2% Occipital Pole, 2% Lateral Occipital Cortex, Inferior Division 2. Left Cerebrum.Temporal Lobe.Middle Temporal Gyrus.Gray Matter.**BA19**
1.3	3.42	-28	-74	22	1. 38% Lateral Occipital Cortex, superior Division 2. Left Cerebrum.Temporal Lobe.Sub-Gyral.White Matter.
1.2	3.38	-28	-76	18	1. 34% Lateral Occipital Cortex, superior Division 2. Left Cerebrum.Occipital Lobe.Middle Occipital Gyrus.White Matter.
1.1	3.25	-44	-80	30	1. 82% Lateral Occipital Cortex, superior Division 2. Left Cerebrum.Temporal Lobe.Middle Temporal Gyrus.White Matter.

Chinese speakers had four clusters of significant activations in contrast to English speakers in this contrast of conditions. The first cluster (4.6 ~ 4.1) is located in the right hemisphere that covers the Lateral Occipital Cortex, the AG, and the temporooccipital part of the MTG including BA 7 and 39. The second cluster (3.6 ~ 3.1) is located in the right hemisphere that covers the MFG and the IFG including BA 45. The third cluster (2.6 ~ 2.1) is located in the left hemisphere that covers the Temporal Occipital Fusiform Cortex, the Occipital Fusiform Gyrus, the Lingual Gyrus, and the posterior division of the Temporal Fusiform Cortex. The forth cluster (1.6 ~ 1.1) is located in the left hemisphere that covers the Lateral Occipital Cortex including BA 19. In contrast to English speakers, Chinese speakers required additional resources in the right hemisphere to differentiate icons from Chinese characters. These regions include the right AG, the right temporooccipital part of the MTG, the right MFG, and the right IFG.

On the other hand, there were no significant activations that formed clusters in the contrasts of English speakers vs. Chinese speakers, which implies that English speakers required fewer brain resources in this condition since English speakers did not need to interprete Chinese characters.

fMRI Data: Chinese Characters vs. Icons

Chinese speakers (n=9), Z: 2.3~6.0

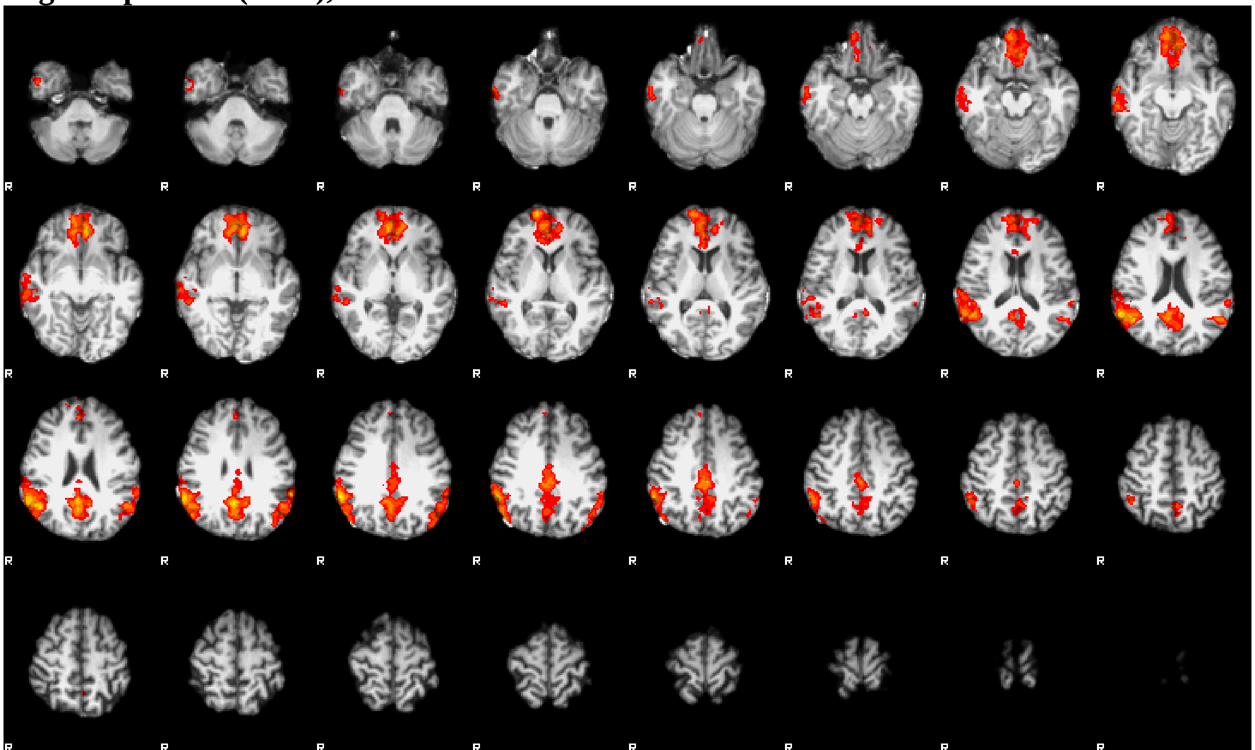


Cluster Index	Z	x	y	z	Brain Areas (Coordinate Space: MNI_152)
4.6	4.52	-10	-60	38	1. 40% Precuneous Cortex, 2% Cingulate Gyrus, posterior division 2. Left Cerebrum.Parietal Lobe.Precuneus.White Matter.
4.5	4.26	6	-26	38	1. 53% Cingulate Gyrus, posterior division, 3% Cingulate Gyrus, anterior division 2. Right Cerebrum.Limbic Lobe.Cingulate Gyrus.Gray Matter.**BA31**
4.4	4.11	2	-28	42	1. 87% Cingulate Gyrus, posterior division, 6% Precuneous Cortex, 1% Cingulate Gyrus, anterior division, 1% Precentral Gyrus 2. Right Cerebrum.Limbic Lobe.Cingulate Gyrus.
4.3	3.85	4	-66	26	1. 62% Precuneous Cortex, 13% Cuneal Cortex, 7% Supracalcarine Cortex 2. Right Cerebrum.Parietal Lobe.Precuneus.
4.2	3.77	-10	-56	28	1. 29% Precuneous Cortex, 19% Cingulate Gyrus, posterior division 2. Left Cerebrum.Parietal Lobe.Precuneus.White Matter.
4.1	3.73	10	-34	46	1. 36% Cingulate Gyrus, posterior division, 24% Precuneous Cortex, 14% Precentral Gyrus, 8% Postcentral Gyrus 2. Right Cerebrum.Parietal Lobe.Precuneus.White Matter.
3.6	4.62	12	44	-10	1. 19% Frontal Medial Cortex, 7% Paracingulate Gyrus 2. Right Cerebrum.Limbic Lobe.Anterior Cingulate.White Matter.
3.5	3.82	10	38	-20	1. 45% Frontal Medial Cortex, 19% Frontal Pole, 2% Frontal Orbital Cortex 2. Right Cerebrum.Frontal Lobe.Medial Frontal Gyrus.White Matter.
3.4	3.71	-8	56	-4	1. 35% Frontal Pole, 24% Frontal Medial Cortex, 13% Paracingulate Gyrus 2. Left Cerebrum.Frontal Lobe.Medial Frontal Gyrus.White Matter.

3.3	3.55	6	52	-16	1. 53% Frontal Medial Cortex, 11% Frontal Pole 2. Right Cerebrum.Frontal Lobe.Medial Frontal Gyrus.Gray Matter.**BA10**
3.2	3.5	18	54	-8	1. 10% Frontal Pole 2. Right Cerebrum.Limbic Lobe.Anterior Cingulate.Gray Matter.**BA10**
3.1	3.34	16	48	0	1. 13% Paracingulate Gyrus, 6% Cingulate Gyrus, anterior division, 1% Frontal Medial Cortex 2. Right Cerebrum.Limbic Lobe.Anterior Cingulate.Gray Matter.**BA32**
2.6	4.52	64	-42	34	1. 61% Supramarginal Gyrus, posterior division, 15% Angular Gyrus, 1% Planum Temporale 2. Right Cerebrum.Parietal Lobe.Supramarginal Gyrus.White Matter.
2.5	4.3	58	-46	28	1. 44% Angular Gyrus, 31% Supramarginal Gyrus, posterior division 2. Right Cerebrum.Parietal Lobe.Supramarginal Gyrus.White Matter.
2.4	4.08	68	-40	30	1. 29% Supramarginal Gyrus, posterior division, 1% Angular Gyrus 2. Right Cerebrum.Parietal Lobe.Inferior Parietal Lobule.Gray Matter.**BA40**
2.3	4.06	66	-48	16	1. 46% Angular Gyrus, 11% Supramarginal Gyrus, posterior division, 8% Middle Temporal Gyrus, temporooccipital part 2. Right Cerebrum.Temporal Lobe.Superior Temporal Gyrus.White Matter.
2.2	3.97	66	-48	20	1. 43% Angular Gyrus, 9% Supramarginal Gyrus, posterior division 2. Right Cerebrum.Temporal Lobe.Superior Temporal Gyrus.White Matter.
2.1	3.97	62	-44	42	1. 41% Supramarginal Gyrus, posterior division, 20% Angular Gyrus 2. Right Cerebrum.Parietal Lobe.Inferior Parietal Lobule.White Matter.
1.3	6.08	-30	-92	-14	1. 39% Occipital Pole, 25% Lateral Occipital Cortex, inferior division, 8% Occipital Fusiform Gyrus 2. Left Cerebrum
1.2	5.29	-22	-98	-12	1. 65% Occipital Pole, 3% Lateral Occipital Cortex, inferior division 2. Left Cerebrum.Occipital Lobe.Fusiform Gyrus.White Matter.
1.1	5.14	-20	-100	-6	1. 65% Occipital Pole, 2% Lateral Occipital Cortex, inferior division 2. Left Cerebrum.Occipital Lobe.Inferior Occipital Gyrus.Gray Matter.**BA17**

In Chinese speakers, significant activations formed four clusters. The first cluster (4.6 ~ 4.1) is located in both right and left hemisphere that covers the posterior division of the Cingulate Gyrus, the Precuneous Cortex, the Precentral Gyrus, and the Cuneal Cortex including BA 31. The second cluster (3.6 ~ 3.1) is located mainly in the right hemisphere that covers the Frontal Pole, the Frontal Medial Cortex, the Paracingulate Gyrus, including BA 10 and 32. The third cluster (2.6 ~ 2.1) is located in the right hemisphere that covers the AG and the posterior division of SMG including BA 40. The fourth cluster (1.3 ~ 1.1) is located in the left hemisphere that covers the Occipital Pole and the inferior devision of the Lateral Occipital Cortex including BA 17. Chinese speakers required the right AG and SMG, the right DMPFC and VMPFC, and the left posterior division of the Cingulate Gyrus to differentiate Chinese characters from icons.

English speakers (n=10), Z: 2.3~6.0

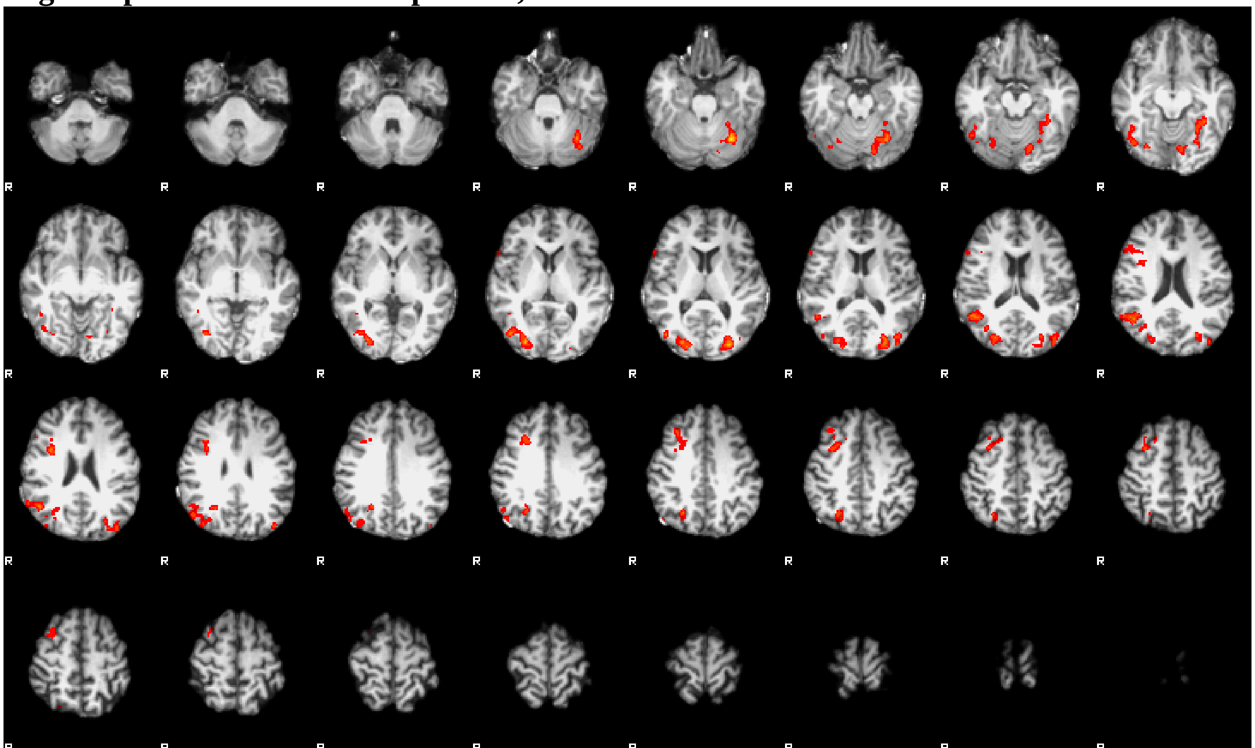


Cluster Index	Z	x	y	z	Brain Areas (Coordinate Space: MNI_152)
4.6	5.31	-6	46	-6	1. 63% Paracingulate Gyrus, 17% Frontal Medial Cortex, 5% Cingulate Gyrus, anterior division 2. Left Cerebrum.Limbic Lobe.Anterior Cingulate.Gray Matter.**BA32**
4.5	4.99	14	66	4	1. 57% Frontal Pole 2. Right Cerebrum.Frontal Lobe.Medial Frontal Gyrus.White Matter.
4.4	4.8	6	48	0	1. 69% Paracingulate Gyrus, 17% Cingulate Gyrus, anterior division, 6% Frontal Medial Cortex 2. Right Cerebrum.Limbic Lobe.Anterior Cingulate.White Matter.
4.3	4.52	6	48	-4	1. 72% Paracingulate Gyrus, 13% Frontal Medial Cortex, 5% Cingulate Gyrus, anterior division 2. Right Cerebrum.Limbic Lobe.Anterior Cingulate.Gray Matter.**BA32**
4.2	4.45	-12	52	0	1. 31% Paracingulate Gyrus, 10% Frontal Medial Cortex, 7% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Medial Frontal Gyrus.White Matter.
4.1	4.45	12	54	-14	1. 6% Frontal Pole, 1% Frontal Medial Cortex 2. Right Cerebrum.Frontal Lobe.Medial Frontal Gyrus.Gray Matter.**BA10**
3.6	5.79	62	-46	30	1. 43% Angular Gyrus, 40% Supramarginal Gyrus, posterior division 2. Right Cerebrum.Parietal Lobe.Supramarginal Gyrus.White Matter.
3.5	5.41	62	-50	22	1. 74% Angular Gyrus, 7% Supramarginal Gyrus, posterior division 2. Right Cerebrum.Temporal Lobe.Superior Temporal Gyrus.White Matter.
3.4	5.36	48	-58	24	1. 30% Angular Gyrus, 21% Lateral Occipital Cortex, superior division, 1% Lateral Occipital Cortex, inferior division, 1% Middle Temporal Gyrus, temporooccipital part 2. Right Cerebrum.Temporal Lobe.Superior Temporal Gyrus.
3.3	4.86	62	-42	38	1. 64% Supramarginal Gyrus, posterior division, 18% Angular Gyrus,

					1% Parietal Operculum Cortex 2. Right Cerebrum.Parietal Lobe.Supramarginal Gyrus.White Matter.
3.2	4.36	56	-64	34	1. 54% Lateral Occipital Cortex, superior division, 5% Angular Gyrus 2. Right Cerebrum.Parietal Lobe.Angular Gyrus.White Matter.
3.1	4.33	50	-72	36	1. 52% Lateral Occipital Cortex, superior division 2. Right Cerebrum.Temporal Lobe.Angular Gyrus.Gray Matter.**BA39**
2.6	5.62	4	-52	28	1. 54% Cingulate Gyrus, posterior division, 35% Precuneous Cortex 2. Right Cerebrum.Limbic Lobe.Posterior Cingulate.
2.5	5.01	4	-50	22	1. 67% Cingulate Gyrus, posterior division, 18% Precuneous Cortex 2. Right Cerebrum.Limbic Lobe.Posterior Cingulate.Gray Matter.**BA30**
2.4	4.84	4	-62	26	1. 77% Precuneous Cortex, 3% Supracalcarine Cortex, 3% Cuneal Cortex 2. Right Cerebrum.Parietal Lobe.Precuneus.
2.3	4.84	0	-28	42	1. 86% Cingulate Gyrus, posterior division, 4% Precuneous Cortex 2. Left Cerebrum.Limbic Lobe.Cingulate Gyrus.
2.2	4.59	6	-56	20	1. 47% Precuneous Cortex, 14% Cingulate Gyrus, posterior division, 4% Supracalcarine Cortex, 1% Intracalcarine Cortex 2. Right Cerebrum.Limbic Lobe.Posterior Cingulate.Gray Matter.**BA23**
2.1	4.53	6	-32	38	1. 64% Cingulate Gyrus, posterior division, 4% Precuneous Cortex 2. Right Cerebrum.Limbic Lobe.Cingulate Gyrus.Gray Matter.**BA31**
1.6	4.6	-62	-42	28	1. 45% Supramarginal Gyrus, posterior division, 19% Supramarginal Gyrus, anterior division, 13% Parietal Operculum Cortex, 4% Angular Gyrus, 4% Superior Temporal Gyrus, posterior division, 3% Planum Temporale 2. Left Cerebrum.Parietal Lobe.Inferior Parietal Lobule.Gray Matter.**BA40**
1.5	4.55	-56	-56	22	1. 64% Angular Gyrus, 12% Supramarginal Gyrus, posterior division, 11% Lateral Occipital Cortex, superior division, 1% Middle Temporal Gyrus, temporooccipital part 2. Left Cerebrum.Temporal Lobe.Superior Temporal Gyrus.White Matter.
1.4	3.85	-52	-66	32	1. 86% Lateral Occipital Cortex, superior division, 6% Angular Gyrus 2. Left Cerebrum.Temporal Lobe.Middle Temporal Gyrus.Gray Matter.**BA39**
1.3	3.83	-44	-78	30	1. 90% Lateral Occipital Cortex, superior division 2. Left Cerebrum.Temporal Lobe.Middle Temporal Gyrus.White Matter.
1.2	3.49	-64	-38	20	1. 25% Parietal Operculum Cortex, 20% Superior Temporal Gyrus, posterior division, 15% Planum Temporale, 12% Supramarginal Gyrus, posterior division, 5% Supramarginal Gyrus, anterior division 2. Left Cerebrum.Temporal Lobe.Superior Temporal Gyrus.Gray Matter.**BA22**
1.1	3.28	-44	-70	30	1. 61% Lateral Occipital Cortex, superior division 2. Left Cerebrum.Temporal Lobe.Middle Temporal Gyrus.White Matter.

In English speakers, significant activations formed four clusters. The first cluster (4.6 ~ 4.1) is located in both right and left hemisphere that covers the Paracingulate Gyrus, the Frontal Pole, the Frontal Medial Cortex, and the anterior division of the Cingulate Gyrus including BA 10 and 32. The second cluster (3.6 ~ 3.1) is located in the right hemisphere that covers the superior division of the Lateral Occipital Cortex, the AG, and the posterior division of the SMG including BA 39. The third cluster (2.6 ~ 2.1) is located in both right and left hemisphere that covers the posterior division of the Cingulate Gyrus, the Precuneous Cortex, including BA 23, 30, and 31. The fourth cluster (1.6 ~ 1.1) is located in the left hemisphere that covers the superior division of the Lateral Occipital Cortex, the AG, the SMG, the posterior division of the STG, the Parietal Operculum Cortex, and the Planum Temporale including BA 22, 39, and 40. The English participants required bilateral activation of the VMPFC, the DMPFC, the AG, the SMG, and the posterior division of the Cingulate Gyrus to differentiate Chinese characters from icons.

English speakers vs. Chinese speakers, Z: 2.3~6.0



Cluster Index	Z	x	y	z	Brain Areas (Coordinate Space: MNI_152)
4.6	5.16	28	-82	4	1. 12% Lateral Occipital Cortex, inferior division, 4% Lateral Occipital Cortex, superior division, 1% Occipital Pole, 1% Occipital Fusiform Gyrus 2. Right Cerebrum.Occipital Lobe.Sub-Gyral.White Matter.
4.5	4.54	46	-74	6	1. 59% Lateral Occipital Cortex, inferior division, 1% Lateral Occipital Cortex, superior division 2. Right Cerebrum.Occipital Lobe.Middle Occipital Gyrus.White Matter.
4.4	4.2	48	-56	22	1. 36% Angular Gyrus, 7% Lateral Occipital Cortex, superior division, 3% Middle Temporal Gyrus, temporooccipital part 2. Right Cerebrum.Temporal Lobe.Superior Temporal Gyrus.Gray Matter.**BA39**
4.3	4.04	52	-52	18	1. 54% Angular Gyrus, 14% Middle Temporal Gyrus, temporooccipital part, 4% Supramarginal Gyrus, posterior division 2. Right Cerebrum.Temporal Lobe.Superior Temporal Gyrus.White Matter.
4.2	3.93	36	-72	-2	1. 6% Lateral Occipital Cortex, inferior division, 4% Occipital Fusiform Gyrus 2. Right Cerebrum.Occipital Lobe.Sub-Gyral.White Matter.
4.1	3.91	26	-64	40	1. 54% Lateral Occipital Cortex, superior division, 2% Precuneous Cortex, 1% Angular Gyrus 2. Right Cerebrum.Parietal Lobe.Precuneus.Gray Matter.**BA7**

3.6	4	36	10	24	1. 15% Inferior Frontal Gyrus, pars opercularis, 6% Precentral Gyrus, 2% Middle Frontal Gyrus 2. Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
3.5	3.75	28	22	36	1. 16% Middle Frontal Gyrus, 4% Superior Frontal Gyrus 2. Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
3.4	3.59	34	10	44	1. 22% Middle Frontal Gyrus, 1% Precentral Gyrus 2. Right Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
3.3	3.47	34	10	54	1. 25% Middle Frontal Gyrus, 5% Superior Frontal Gyrus, 3% Precentral Gyrus 2. Right Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
3.2	3.33	60	22	6	1. 12% Inferior Frontal Gyrus, pars triangularis, 11% Inferior Frontal Gyrus, pars opercularis 2. Right Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.Gray Matter.**BA45**
3.1	3.23	28	12	42	1. 13% Middle Frontal Gyrus, 3% Superior Frontal Gyrus, 1% Precentral Gyrus 2. Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
2.6	5.48	-30	-64	-24	1. No label found 2. Left Cerebellum.Anterior Lobe.Culmen.Gray Matter.
2.5	4.08	-14	-78	-18	1. 15% Occipital Fusiform Gyrus, 14% Lingual Gyrus 2. Left Cerebellum.Posterior Lobe.Declive.Gray Matter.
2.4	3.93	-36	-44	-12	1. 11% Temporal Occipital Fusiform Cortex, 10% Temporal Fusiform Cortex, posterior division, 1% Lingual Gyrus, 1% Parahippocampal Gyrus, posterior division 2. Left Cerebrum.Temporal Lobe.Fusiform Gyrus.White Matter.
2.3	3.57	-34	-72	-26	1. 1% Occipital Fusiform Gyrus 2. Left Cerebellum.Posterior Lobe.Uvula.Gray Matter.
2.2	3.47	-8	-76	-12	1. 54% Lingual Gyrus, 13% Occipital Fusiform Gyrus 2. Left Cerebellum.Posterior Lobe.Declive.Gray Matter.
2.1	3.35	-28	-54	-12	1. 50% Temporal Occipital Fusiform Cortex, 3% Lingual Gyrus, 1% Occipital Fusiform Gyrus, 1% Temporal Fusiform Cortex, posterior division, 1% Inferior Temporal Gyrus, temporooccipital part 2. Left Cerebellum.Posterior Lobe.Declive.Gray Matter.
1.6	4.67	-28	-86	8	1. 24% Lateral Occipital Cortex, inferior division, 17% Lateral Occipital Cortex, superior division, 5% Occipital Pole 2. Left Cerebrum.Occipital Lobe.Middle Occipital Gyrus.White Matter.
1.5	3.72	-42	-84	16	1. 58% Lateral Occipital Cortex, superior division, 17% Lateral Occipital Cortex, inferior division, 2% Occipital Pole 2. Left Cerebrum.Occipital Lobe.Middle Occipital Gyrus.White Matter.
1.4	3.69	-40	-84	22	1. 73% Lateral Occipital Cortex, superior division, 2% Occipital Pole, 2% Lateral Occipital Cortex, inferior division 2. Left Cerebrum.Temporal Lobe.Middle Temporal Gyrus.Gray Matter.**BA19**
1.3	3.42	-28	-74	22	1. 38% Lateral Occipital Cortex, superior division 2. Left Cerebrum.Temporal Lobe.Sub-Gyral.White Matter.
1.2	3.38	-28	-76	18	1. 34% Lateral Occipital Cortex, superior division 2. Left Cerebrum.Occipital Lobe.Middle Occipital Gyrus.White Matter.
1.1	3.25	-44	-80	30	1. 82% Lateral Occipital Cortex, superior division 2. Left Cerebrum.Temporal Lobe.Middle Temporal Gyrus.White Matter.

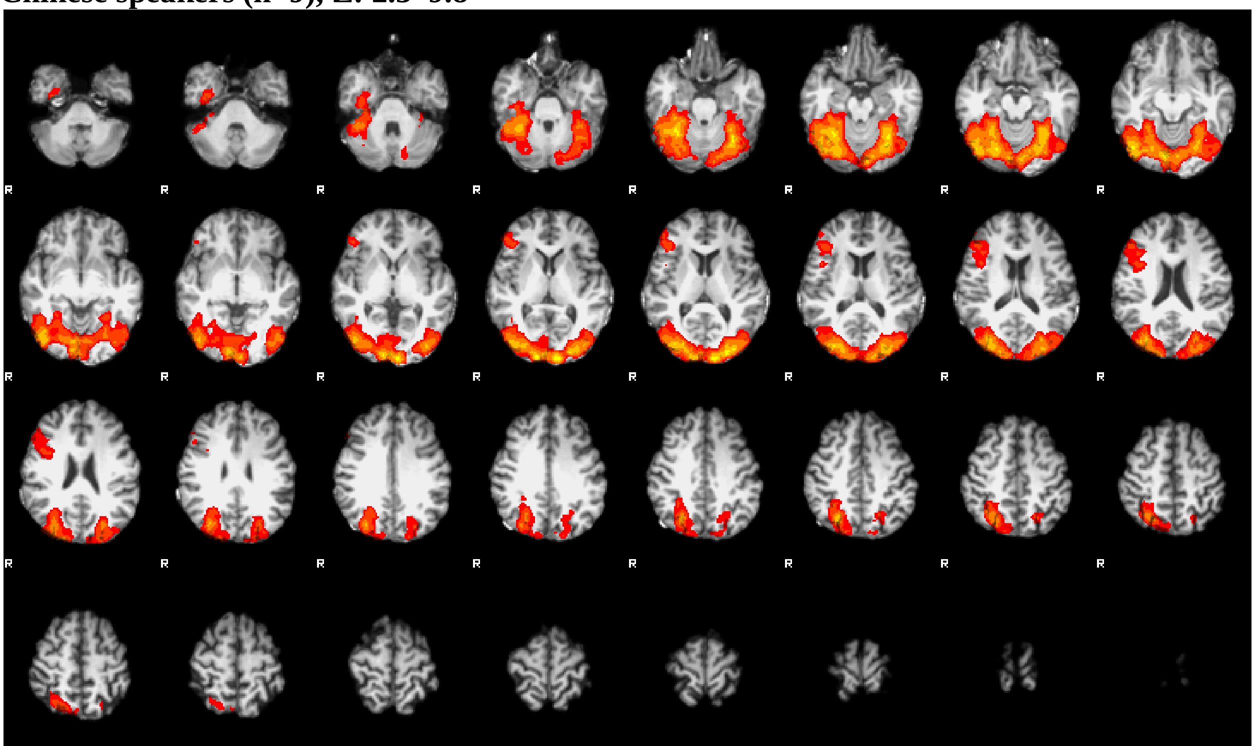
English speakers had four clusters of significant activations in contrast to Chinese speakers in this contrast of conditions. The first cluster (4.6 ~ 4.1) is located in the right hemisphere that covers the Lateral Occipital Cortex, the AG, and the temporooccipital part of the

MTG including BA 7 and 39. The second cluster (3.6 ~ 3.1) is located in the right hemisphere that covers the MFG, and the IFG including BA 45. The third cluster (2.6 ~ 2.1) is located in the left hemisphere that covers the Temporal Occipital Fusiform Cortex, the Occipital Fusiform Gyrus, the Lingual Gyrus, and the posterior division of the Temporal Fusiform Cortex. The forth cluster (1.6 ~ 1.1) is located in the left hemisphere that covers the Lateral Occipital Cortex including BA 19.

There were no significant activations that formed clusters in the contrast of Chinese speakers vs. English speakers, whereas English speakers required more resources in the AG, the temporooccipital part of the MTG, the MFG, and the IFG in the right hemisphere to differentiate Chinese characters and icons than Chinese speakers.

fMRI Data: Icons vs. English Words

Chinese speakers (n=9), Z: 2.3~9.8

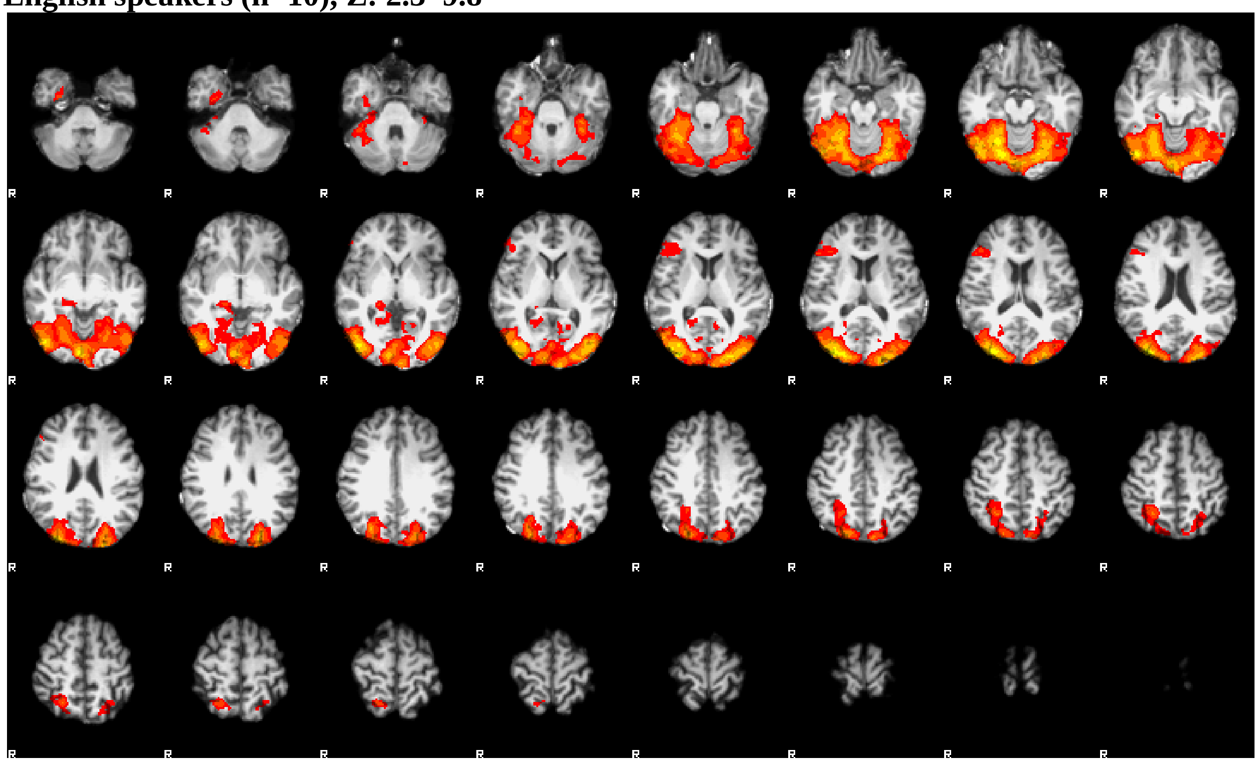


Cluster Index	Z	x	y	z	Brain Areas (Coordinate Space: MNI_152)
2.6	9.75	-12	-100	6	1. 52% Occipital Pole, 1% Cuneal Cortex, 1% Lateral Occipital Cortex, superior Division 2. Left Cerebrum.Occipital Lobe.Cuneus.Gray Matter.
2.5	9.44	-4	-98	0	1. 66% Occipital Pole, 3% Lingual Gyrus 2. Left Cerebrum.Occipital Lobe.Lingual Gyrus.White Matter.
2.4	9.17	-24	-92	6	1. 28% Occipital Pole, 9% Lateral Occipital Cortex, Inferior Division, 4% Lateral Occipital Cortex, superior Division 2. Left Cerebrum.Occipital Lobe.Middle Occipital Gyrus.White Matter.
2.3	9.06	14	-98	4	1. 76% Occipital Pole 2. Right Cerebrum.Occipital Lobe.Lingual Gyrus.Gray Matter.**BA17**
2.2	9.06	32	-56	-22	1. 6% Temporal Occipital Fusiform Cortex 2. Right Cerebellum.Anterior Lobe.Culmen.Gray Matter.

2.1	9.05	24	-72	-14	1. 66% Occipital Fusiform Gyrus, 12% Lingual Gyrus 2. Right Cerebellum.Posterior Lobe.Declive.Gray Matter.
1.6	5.55	44	32	10	1. 18% Inferior Frontal Gyrus, pars triangularis, 10% Frontal Pole, 3% Middle Frontal Gyrus 2. Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
1.5	4.95	46	34	16	1. 32% Inferior Frontal Gyrus, pars triangularis, 20% Frontal Pole, 17% Middle Frontal Gyrus 2. Right Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
1.4	4.74	48	38	4	1. 49% Frontal Pole, 16% Inferior Frontal Gyrus, pars triangularis 2. Right Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
1.3	4.7	42	12	18	1. 9% Inferior Frontal Gyrus, pars opercularis, 4% Precentral Gyrus, 1% Frontal Operculum Cortex, 1% Middle Frontal Gyrus 2. Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
1.2	4.65	44	10	22	1. 29% Inferior Frontal Gyrus, pars opercularis, 12% Precentral Gyrus, 1% Middle Frontal Gyrus 2. Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
1.1	4.62	40	24	18	1. 9% Inferior Frontal Gyrus, pars opercularis, 8% Inferior Frontal Gyrus, pars triangularis, 5% Middle Frontal Gyrus 2. Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.

In Chinese speakers, significant activations formed two clusters. The first cluster (2.6 ~ 2.1) is located in both right and left hemisphere that covers the Occipital Pole, the Lingual Gyrus, and the Occipital Fusiform Gyrus including BA 17. The second cluster (1.6 ~ 1.1) is located in the right hemisphere that covers the MFG, the IFG, the Frontal Pole, and the Precentral Gyrus. Chinese speakers required the MFG, the IFG, and the Frontal Pole in the right hemisphere to differentiate icons from English words.

English speakers (n=10), Z: 2.3~9.8



Cluster Index	Z	x	y	z	Brain Areas (Coordinate Space: MNI_152)
2.6	9.88	24	-72	-16	1. 50% Occipital Fusiform Gyrus, 8% Lingual Gyrus 2. Right Cerebellum.Posterior Lobe.Declive.Gray Matter.
2.5	9.87	32	-88	18	1. 40% Lateral Occipital Cortex, superior Division, 33% Occipital Pole, 4% Lateral Occipital Cortex, Inferior Division 2. Right Cerebrum.Occipital Lobe.Middle Occipital Gyrus.White Matter.
2.4	9.64	28	-58	-16	1. 51% Temporal Occipital Fusiform Cortex, 12% Occipital Fusiform Gyrus, 5% Lingual Gyrus 2. Right Cerebellum.Posterior Lobe.Declive.Gray Matter.
2.3	9.54	24	-90	12	1. 25% Occipital Pole, 12% Lateral Occipital Cortex, superior Division, 1% Lateral Occipital Cortex, Inferior Division 2. Right Cerebrum.Occipital Lobe.Cuneus.White Matter.
2.2	9.33	34	-90	10	1. 44% Occipital Pole, 18% Lateral Occipital Cortex, superior Division, 10% Lateral Occipital Cortex, Inferior Division 2. Right Cerebrum.Occipital Lobe.Middle Occipital Gyrus.White Matter.
2.1	9.13	44	-86	2	1. 56% Lateral Occipital Cortex, Inferior Division, 10% Occipital Pole, 4% Lateral Occipital Cortex, superior Division 2. Right Cerebrum.Occipital Lobe.Middle Occipital Gyrus.White Matter.
1.4	4.36	46	30	16	1. 31% Inferior Frontal Gyrus, pars triangularis, 14% Middle Frontal Gyrus, 3% Frontal Pole, 2% Inferior Frontal Gyrus, pars opercularis 2. Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
1.3	4.33	54	28	12	1. 46% Inferior Frontal Gyrus, pars triangularis, 10% Inferior Frontal Gyrus, pars opercularis, 2% Frontal Pole 2. Right Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
1.2	3.93	46	36	6	1. 28% Frontal Pole, 17% Inferior Frontal Gyrus, pars triangularis, 1% Middle Frontal Gyrus 2. Right Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
1.1	3.32	56	40	4	1. 24% Frontal Pole, 4% Inferior Frontal Gyrus, pars triangularis 2. Right Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.

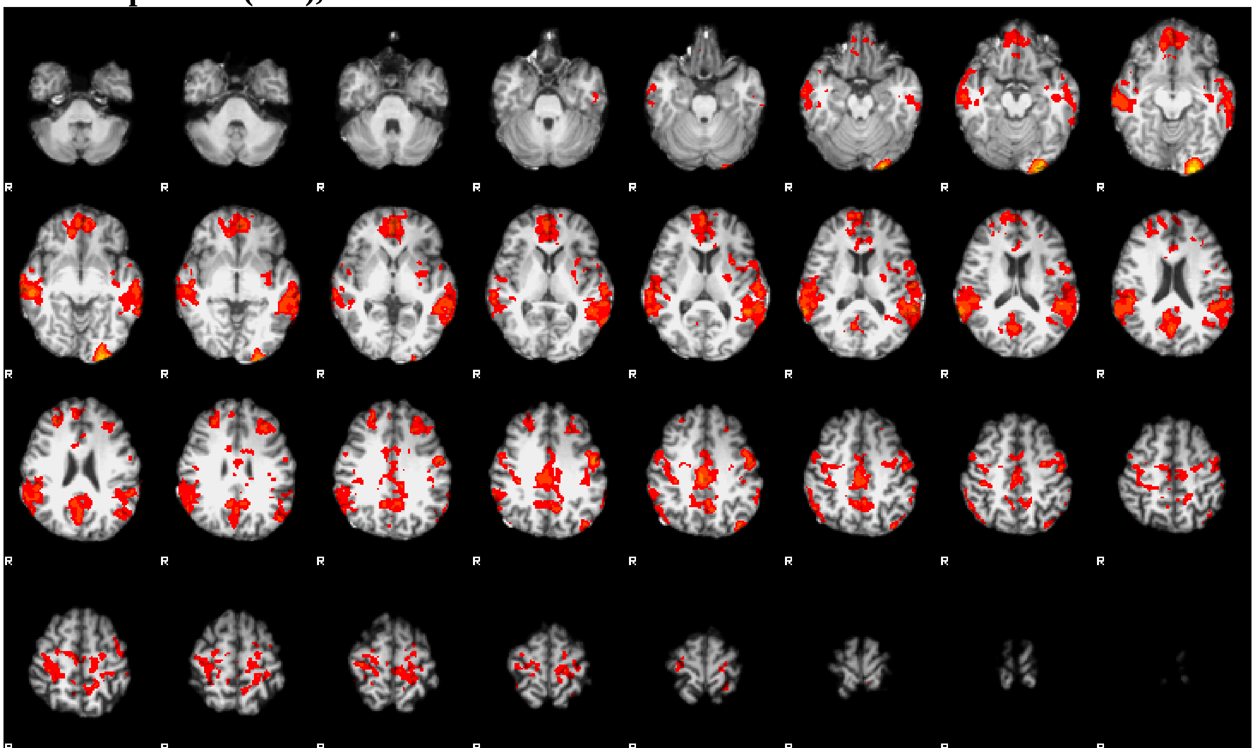
In English speakers, significant activations formed two clusters. The first cluster (2.6 ~ 2.1) is located in the right hemisphere that covers the Lateral Occipital Cortex, the Occipital Fusiform Gyrus, the Occipital Pole, the Temporal Occipital Fusiform Cortex, and the Lingual Gyrus. The second cluster (1.4 ~ 1.1) is located in the right hemisphere that covers the Frontal Pole, the IFG, and the MFG. Similar to the Chinese participants, the English speakers also required resources in the right hemisphere including the IFG, the MFG, and the Frontal Pole to differentiate icons from English words.

As for the group comparison, Chinese speakers had one cluster of significant activations in contrast to English speakers in this contrast of conditions. This cluster is located in both right and left hemisphere that covers the Occipital Pole, the Lateral Occipital Cortex, and the Occipital Fusiform Gyrus including BA 17, 18, 19. This implied that Chinese speakers relied more on the visual cortexes than English speakers to interprete icons in contrast to English words. On the other hand, English speakers had three clusters of significant activations in contrast to Chinese speakers in this contrast of conditions. The first cluster is located in the right hemisphere that covers the Lateral Occipital Cortex and the Occipital Pole including BA 19 and 37. The second cluster is located in the right hemisphere that covers the Precentral Gyrus, and the Postcentral Gyrus including BA 4. The third cluster is located in the left hemisphere that covers the Occipital

Pole and the Lateral Occipital Cortex including BA 18 and 19. Other than the visual cortexes, the motor cortexes in English speakers were more active than Chinese speakers when differentiating icons from English words. These findings in group comparisons were less significant.

fMRI Data: English Words vs. Icons

Chinese speakers (n=9), Z: 2.3~8.4



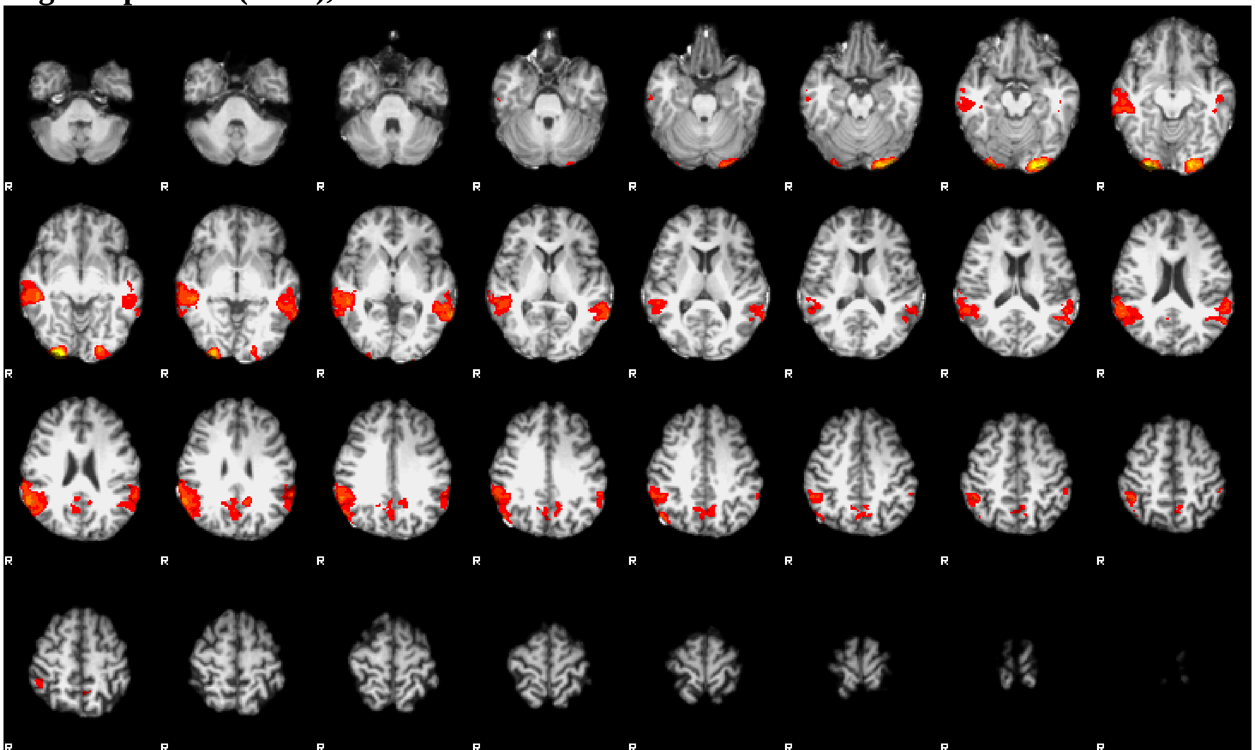
Cluster Index	Z	x	y	z	Brain Areas (Coordinate Space: MNI_152)
5.6	5.85	66	-46	14	1. 40% Angular Gyrus, 22% Supramarginal Gyrus, posterior division, 14% Middle Temporal Gyrus, temporooccipital part 2. Right Cerebrum.Temporal Lobe.Superior Temporal Gyrus.White Matter.
5.5	5.5	58	-26	-8	1. 58% Middle Temporal Gyrus, posterior division, 8% Superior Temporal Gyrus, posterior division, 1% Supramarginal Gyrus, posterior division, 1% Middle Temporal Gyrus, temporooccipital part 2. Right Cerebrum.Temporal Lobe.Middle Temporal Gyrus.White Matter.
5.4	5.34	-52	-4	38	1. 60% Precentral Gyrus, 2% Middle Frontal Gyrus, 1% Postcentral Gyrus 2. Left Cerebrum.Frontal Lobe.Precentral Gyrus.White Matter.
5.3	5.29	-48	-46	8	1. 22% Middle Temporal Gyrus, temporooccipital part, 19% Supramarginal Gyrus, posterior division, 9% Superior Temporal Gyrus, posterior division, 6% Angular Gyrus, 1% Middle Temporal Gyrus, posterior division 2. Left Cerebrum.Temporal Lobe.Middle Temporal Gyrus.White Matter.
5.2	5.1	6	-20	40	1. 58% Cingulate Gyrus, posterior division, 9% Cingulate Gyrus, anterior division, 2% Precentral Gyrus 2. Right Cerebrum.Limbic Lobe.Cingulate Gyrus.
5.1	5.1	50	-32	22	1. 54% Parietal Operculum Cortex, 17% Planum Temporale, 5%

					Supramarginal Gyrus, posterior division, 3% Supramarginal Gyrus, anterior division 2. Right Cerebrum.Sub-lobar.Insula.Gray Matter.**BA13**
4.6	4.6	4	54	2	1. 62% Paracingulate Gyrus, 26% Frontal Pole, 6% Frontal Medial Cortex 2. Right Cerebrum.Frontal Lobe.Medial Frontal Gyrus.
4.5	4.6	2	46	0	1. 52% Paracingulate Gyrus, 36% Cingulate Gyrus, anterior division, 3% Frontal Medial Cortex 2. Inter-Hemispheric.
4.4	4.47	12	46	-10	1. 21% Frontal Medial Cortex, 8% Paracingulate Gyrus 2. Right Cerebrum.Limbic Lobe.Anterior Cingulate.White Matter.
4.3	4.46	-6	56	-4	1. 43% Frontal Pole, 26% Frontal Medial Cortex, 15% Paracingulate Gyrus 2. Left Cerebrum.Frontal Lobe.Medial Frontal Gyrus.White Matter.
4.2	4.28	2	64	12	1. 63% Frontal Pole 2. Inter-Hemispheric.
4.1	4.19	4	56	-8	1. 57% Frontal Pole, 27% Frontal Medial Cortex, 8% Paracingulate Gyrus 2. Right Cerebrum.Limbic Lobe.Anterior Cingulate.Gray Matter.**BA10**
3.5	8.27	-22	-100	-12	1. 63% Occipital Pole, 2% Lateral Occipital Cortex, inferior division 2. Left Cerebrum.Occipital Lobe.Fusiform Gyrus.Gray Matter.**BA18**
3.4	7.19	-28	-100	-14	1. 23% Occipital Pole 2. Left Cerebrum
3.3	7.02	-26	-98	-18	1. 23% Occipital Pole, 2% Lateral Occipital Cortex, inferior division, 1% Occipital Fusiform Gyrus 2. Left Cerebrum
3.2	6.72	-28	-92	-16	1. 36% Occipital Pole, 20% Lateral Occipital Cortex, inferior division, 10% Occipital Fusiform Gyrus 2. Left Cerebrum.Occipital Lobe.Fusiform Gyrus.Gray Matter.**BA18**
3.1	6.43	-24	-90	-10	1. 23% Occipital Fusiform Gyrus, 20% Occipital Pole, 15% Lateral Occipital Cortex, inferior division 2. Left Cerebrum.Occipital Lobe.Inferior Occipital Gyrus.Gray Matter.**BA18**
2.6	4.34	30	42	26	1. 62% Frontal Pole, 7% Middle Frontal Gyrus 2. Right Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
2.5	3.95	24	50	32	1. 80% Frontal Pole 2. Right Cerebrum.Frontal Lobe.Superior Frontal Gyrus.Gray Matter.**BA9**
2.4	3.79	24	40	34	1. 40% Frontal Pole, 9% Middle Frontal Gyrus, 8% Superior Frontal Gyrus 2. Right Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
2.3	3.78	26	44	34	1. 70% Frontal Pole, 3% Middle Frontal Gyrus, 1% Superior Frontal Gyrus 2. Right Cerebrum.Frontal Lobe.Middle Frontal Gyrus.Gray Matter.**BA9**
2.2	2.69	26	58	22	1. 88% Frontal Pole 2. Right Cerebrum.Frontal Lobe.Superior Frontal Gyrus.White Matter.
2.1	2.48	28	52	14	1. 75% Frontal Pole 2. Right Cerebrum.Frontal Lobe.Superior Frontal Gyrus.Gray Matter.**BA10**
1.6	4.21	-30	36	28	1. 30% Middle Frontal Gyrus, 23% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
1.5	4.2	-24	34	32	1. 28% Middle Frontal Gyrus, 13% Superior Frontal Gyrus, 9% Frontal

					Pole 2. Left Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
1.4	3.83	-32	32	28	1. 19% Middle Frontal Gyrus, 6% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
1.3	3.54	-26	46	32	1. 80% Frontal Pole 2. Left Cerebrum.Frontal Lobe.Middle Frontal Gyrus.Gray Matter.**BA9**
1.2	3.07	-40	32	30	1. 57% Middle Frontal Gyrus, 8% Frontal Pole, 1% Inferior Frontal Gyrus, pars triangularis 2. Left Cerebrum.Frontal Lobe.Middle Frontal Gyrus.White Matter.
1.1	2.86	-22	38	20	1. 5% Frontal Pole, 3% Middle Frontal Gyrus 2. Left Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.

In Chinese speakers, significant activations formed five clusters. The first cluster (5.6 ~ 5.1) is located in both right and left hemisphere that covers the MTG, the posterior division of the Cingulate Gyrus, the Precentral Gyrus, the AG, the posterior division of the SMG, the Parietal Operculum Cortex, and the Planum Temporale including BA 13. The second cluster (4.6 ~ 4.1) is located in both right and left hemisphere that covers the Paracingulate Gyrus, the Frontal Pole, the Frontal Medial Cortex, and the anterior division of the Cingulate Gyrus including BA 10. The third cluster (3.5 ~ 3.1) is located in the left hemisphere that covers the Occipital Pole, the inferior division of the Lateral Occipital Cortex, and the Occipital Fusiform Gyrus including BA 18. The fourth cluster (2.6 ~ 2.1) is located in the right hemisphere that covers the Frontal Pole including BA 9 and 10. The fifth cluster (1.6 ~ 1.1) is located in the left hemisphere that covers the Frontal Pole, the MFG, and SFG including BA 9. The Chinese participants used resources in the left DMPFC, bilateral activations in the AG, the posterior and temporooccipital part of the MTG, the posterior division of the SMG, the Parietal Operculum Cortex, and the Planum Temporale, and the left posterior division of the Cingulate Gyrus to differentiate English words from icons.

English speakers (n=10), Z: 2.3~8.4



Cluster Index	Z	x	y	z	Brain Areas (Coordinate Space: MNI_152)
5.6	5.65	62	-52	24	1. 71% Angular Gyrus, 4% Supramarginal Gyrus, posterior division, 1% Lateral Occipital Cortex, superior division 2. Right Cerebrum.Temporal Lobe.Supramarginal Gyrus.White Matter.
5.5	5.48	52	-32	-6	1. 50% Middle Temporal Gyrus, posterior division, 6% Middle Temporal Gyrus, temporooccipital part, 1% Superior Temporal Gyrus, posterior division 2. Right Cerebrum.Temporal Lobe.Middle Temporal Gyrus.White Matter.
5.4	5.09	50	-28	-8	1. 52% Middle Temporal Gyrus, posterior division, 4% Middle Temporal Gyrus, temporooccipital part, 3% Superior Temporal Gyrus, posterior division 2. Right Cerebrum.Temporal Lobe.Middle Temporal Gyrus.White Matter.
5.3	5.08	54	-38	-2	1. 25% Middle Temporal Gyrus, temporooccipital part, 24% Middle Temporal Gyrus, posterior division, 5% Superior Temporal Gyrus, posterior division, 2% Supramarginal Gyrus, posterior division 2. Right Cerebrum.Temporal Lobe.Middle Temporal Gyrus.White Matter.
5.2	4.8	60	-44	20	1. 42% Supramarginal Gyrus, posterior division, 34% Angular Gyrus 2. Right Cerebrum.Temporal Lobe.Superior Temporal Gyrus.White Matter.
5.1	4.63	62	-36	2	1. 32% Middle Temporal Gyrus, posterior division, 21% Superior Temporal Gyrus, posterior division, 19% Middle Temporal Gyrus, temporooccipital part, 8% Supramarginal Gyrus, posterior division, 1% Angular Gyrus 2. Right Cerebrum.Temporal Lobe.Middle Temporal Gyrus.Gray Matter.**BA22**
4.6	5.71	-66	-52	0	1. 62% Middle Temporal Gyrus, temporooccipital part, 4% Angular

					Gyrus, 1% Middle Temporal Gyrus, posterior division 2. Left Cerebrum.Temporal Lobe.Middle Temporal Gyrus.Gray Matter.**BA21**
4.5	4.78	-60	-42	0	1. 39% Middle Temporal Gyrus, posterior division, 24% Middle Temporal Gyrus, temporooccipital part, 9% Superior Temporal Gyrus, posterior division, 8% Supramarginal Gyrus, posterior division 2. Left Cerebrum.Temporal Lobe.Middle Temporal Gyrus.Gray Matter.**BA21**
4.4	4.36	-58	-54	2	1. 50% Middle Temporal Gyrus, temporooccipital part, 6% Angular Gyrus, 5% Lateral Occipital Cortex, inferior division, 5% Supramarginal Gyrus, posterior division 2. Left Cerebrum.Temporal Lobe.Middle Temporal Gyrus.White Matter.
4.3	4.3	-50	-40	-6	1. 16% Middle Temporal Gyrus, posterior division, 4% Middle Temporal Gyrus, temporooccipital part 2. Left Cerebrum.Temporal Lobe.Sub-Gyral.White Matter.
4.2	4.13	-64	-44	26	1. 45% Supramarginal Gyrus, posterior division, 13% Angular Gyrus, 8% Supramarginal Gyrus, anterior division, 6% Parietal Operculum Cortex, 3% Planum Temporale, 3% Superior Temporal Gyrus, posterior division 2. Left Cerebrum.Parietal Lobe.Inferior Parietal Lobule.Gray Matter.**BA40**
4.1	4.06	-60	-60	18	1. 45% Angular Gyrus, 29% Lateral Occipital Cortex, superior division, 7% Middle Temporal Gyrus, temporooccipital part, 2% Supramarginal Gyrus, posterior division, 1% Lateral Occipital Cortex, inferior division 2. Left Cerebrum.Temporal Lobe.Superior Temporal Gyrus.Gray Matter.**BA22**
3.4	8.28	-20	-96	-14	1. 55% Occipital Pole, 4% Occipital Fusiform Gyrus, 3% Lateral Occipital Cortex, inferior division 2. Left Cerebrum
3.3	8.14	-28	-96	-16	1. 40% Occipital Pole, 5% Lateral Occipital Cortex, inferior division, 3% Occipital Fusiform Gyrus 2. Left Cerebrum.Occipital Lobe.Fusiform Gyrus.Gray Matter.**BA18**
3.2	6.29	-38	-90	-20	1. 11% Lateral Occipital Cortex, inferior division, 5% Occipital Pole, 3% Occipital Fusiform Gyrus 2. Left Cerebellum.Posterior Lobe.Declive.Gray Matter.
3.1	3.11	-24	-104	-4	1. 25% Occipital Pole 2. Left Cerebrum
2.6	4.16	-12	-52	28	1. 21% Cingulate Gyrus, posterior division, 6% Precuneous Cortex 2. Left Cerebrum.Parietal Lobe.Sub-Gyral.White Matter.
2.5	3.64	4	-62	26	1. 77% Precuneous Cortex, 3% Supracalcarine Cortex, 3% Cuneal Cortex 2. Right Cerebrum.Parietal Lobe.Precuneus.
2.4	3.39	4	-52	30	1. 53% Cingulate Gyrus, posterior division, 39% Precuneous Cortex 2. Right Cerebrum.Limbic Lobe.Cingulate Gyrus.
2.3	3.38	-8	-64	38	1. 48% Precuneous Cortex, 1% Lateral Occipital Cortex, superior division 2. Left Cerebrum.Occipital Lobe.Precuneus.
2.2	3.32	6	-48	26	1. 41% Cingulate Gyrus, posterior division, 5% Precuneous Cortex 2. Right Cerebrum.Limbic Lobe.Posterior Cingulate.Gray Matter.**BA23**
2.1	3.29	6	-68	40	1. 63% Precuneous Cortex, 2% Cuneal Cortex, 1% Lateral Occipital Cortex, superior division 2. Right Cerebrum.Parietal Lobe.Precuneus.Gray Matter.**BA7**

1.1	8.4	24	-96	-8	1. 68% Occipital Pole, 2% Lingual Gyrus, 2% Lateral Occipital Cortex, inferior division 2. Right Cerebrum.Occipital Lobe.Inferior Occipital Gyrus.White Matter.

In English speakers, significant activations formed five clusters. The first cluster (5.6 ~ 5.1) is located in the right hemisphere that covers the AG, the posterior division of the SMG, the posterior and temporooccipital part of the MTG, and the posterior division of the STG including BA 22. The second cluster (4.6 ~ 4.1) is located in the left hemisphere that covers the posterior and temporooccipital part of the MTG, the AG, the posterior division of the SMG, and the superior division of the Lateral Occipital Cortex including BA 21, 22, and 40. The third cluster (3.4 ~ 3.1) is located in the left hemisphere that covers the Occipital Pole and the inferior division of the Lateral Occipital Cortex including BA 18. The forth cluster (2.6 ~ 2.1) is located in both right and left hemisphere that covers the Precuneous Cortex and the posterior division of the Cingulate Gyrus including BA 7 and 23. The fifth cluster (1.1) is located in the right hemisphere that covers the Occipital Pole. The English participants used resources in bilateral activations in the AG, the posterior and temporooccipital part of the MTG, the posterior division of the SMG, and the posterior division of the Cingulate Gyrus to differentiate English words from icons.

As for the group comparisons, Chinese speakers had three clusters of significant activations in contrast to English speakers in this contrast of conditions. The first cluster is located in the right hemisphere that covers the Lateral Occipital Cortex and the Occipital Pole including BA 19 and 37. The second cluster is located in the right hemisphere that covers the Precentral Gyrus, and the Postcentral Gyrus including BA 4. The third cluster is located in the left hemisphere that covers the Occipital Pole and the superior division of the Lateral Occipital Cortex including BA 18 and 19. On the other hand, English speakers had one cluster of significant activations in contrast to Chinese speakers in this contrast. This cluster is located in both right and left hemisphere that covers the Occipital Pole, the inferior division of the Lateral Occipital Cortex, and the Occipital Fusiform Gyrus including BA 17, 18, and 19. These findings in the group comparisons were less significant.

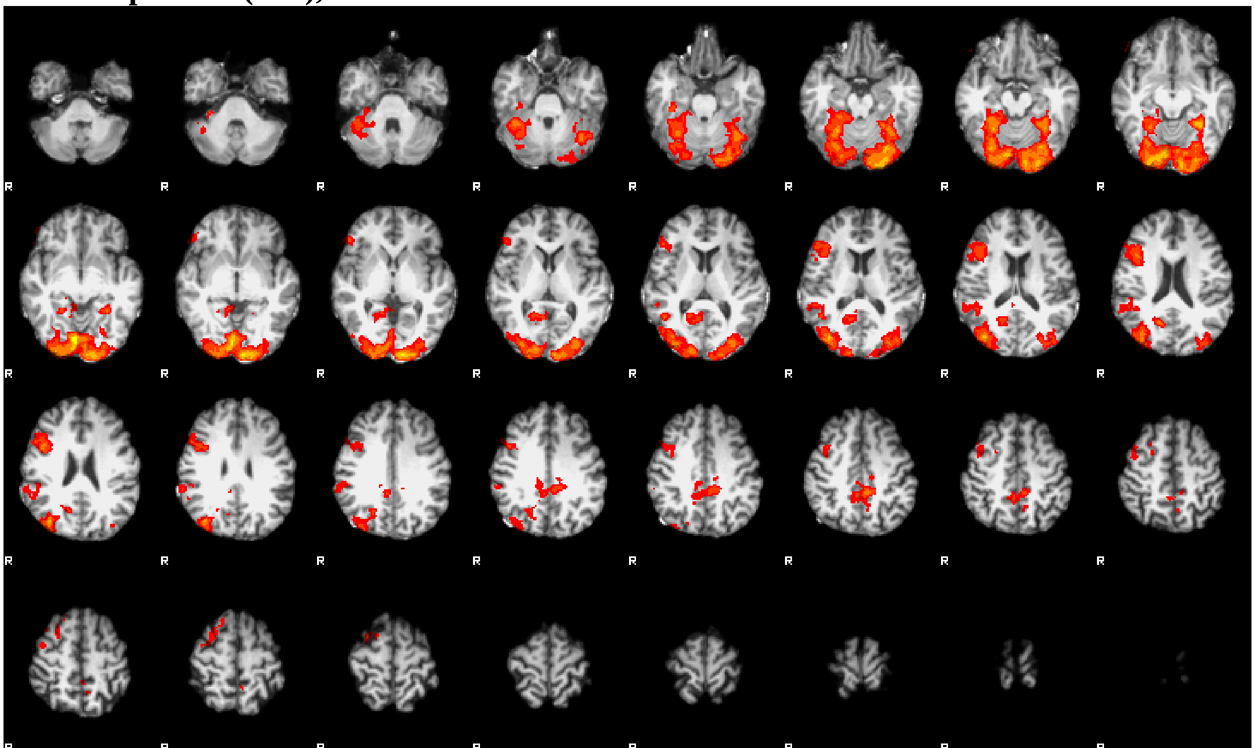
fMRI Data: Icons vs. Pictures

No clusters were found in either Chinese speakers or English speakers. This implied that there were not significant differences in processing icons and pictures in the brains of our English and Chinese participants.

As for the group comparisons, there were also no clusters found in Chinese speakers vs. English speakers: the Chinese participants required no additional resources than the English participants to contrast icons from pictures. On the other hand, English speakers had one cluster of significant activations in contrast to Chinese speakers in this contrast of conditions. This cluster is located in the left hemisphere that covers the Postcentral Gyrus, the Precentral Gyrus, and the Superior Parietal Lobule including BA 4, 5, and 7. It is implied that these extra activations in motor areas were caused by behavioral activities, and such a finding is less significant.

fMRI Data: Pictures vs. Icons

Chinese speakers (n=9), Z: 2.3~7.1



Cluster Index	Z	x	y	z	Brain Areas (Coordinate Space: MNI_152)
3.6	6.81	8	-80	-8	1. 71% Lingual Gyrus, 6% Occipital Fusiform Gyrus, 1% Intracalcarine Cortex 2. Right Cerebrum
3.5	6.61	-6	-98	-4	1. 68% Occipital Pole, 2% Lateral Occipital Cortex, inferior division, 1% Lingual Gyrus, 1% Intracalcarine Cortex 2. Left Cerebrum.Occipital Lobe.Lingual Gyrus.White Matter.
3.4	6.47	-10	-98	-2	1. 67% Occipital Pole, 2% Cuneal Cortex 2. Left Cerebrum.Occipital Lobe.Lingual Gyrus.White Matter.
3.3	6.15	-22	-96	-20	1. 24% Occipital Pole, 3% Occipital Fusiform Gyrus, 3% Lateral Occipital Cortex, inferior division 2. Left Cerebrum
3.2	6.09	20	-86	-14	1. 48% Occipital Fusiform Gyrus, 8% Occipital Pole, 6% Lingual Gyrus, 4% Lateral Occipital Cortex, inferior division 2. Right Cerebellum.Posterior Lobe.Declive.Gray Matter.
3.1	6.07	-30	-48	-12	1. 41% Temporal Occipital Fusiform Cortex, 11% Temporal Fusiform Cortex, posterior division, 3% Lingual Gyrus 2. Left Cerebrum.Temporal Lobe.Fusiform Gyrus.Gray Matter.**BA37**
2.6	4.73	46	12	26	1. 30% Inferior Frontal Gyrus, pars opercularis, 19% Precentral Gyrus, 5% Middle Frontal Gyrus 2. Right Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
2.5	4.43	42	18	20	1. 15% Inferior Frontal Gyrus, pars opercularis, 3% Middle Frontal Gyrus, 2% Precentral Gyrus 2. Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
2.4	4.18	50	30	10	1. 40% Inferior Frontal Gyrus, pars triangularis, 4% Frontal Pole, 1% Inferior Frontal Gyrus, pars opercularis

					2. Right Cerebrum.Frontal Lobe.Inferior Frontal Gyrus.White Matter.
2.3	4.16	44	24	14	1. 15% Inferior Frontal Gyrus, pars triangularis, 5% Inferior Frontal Gyrus, pars opercularis, 2% Precentral Gyrus, 1% Middle Frontal Gyrus 2. Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
2.2	3.94	40	28	12	1. 11% Inferior Frontal Gyrus, pars triangularis, 1% Inferior Frontal Gyrus, pars opercularis 2. Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
2.1	3.88	40	28	18	1. 17% Inferior Frontal Gyrus, pars triangularis, 12% Middle Frontal Gyrus, 6% Inferior Frontal Gyrus, pars opercularis, 1% Frontal Pole 2. Right Cerebrum.Frontal Lobe.Sub-Gyral.White Matter.
1.6	4.32	48	-54	10	1. 39% Middle Temporal Gyrus, temporooccipital part, 7% Angular Gyrus, 3% Lateral Occipital Cortex, inferior division, 1% Lateral Occipital Cortex, superior division 2. Right Cerebrum.Temporal Lobe.Middle Temporal Gyrus.White Matter.
1.5	3.72	46	-46	14	1. 23% Middle Temporal Gyrus, temporooccipital part, 18% Angular Gyrus, 17% Supramarginal Gyrus, posterior division 2. Right Cerebrum.Temporal Lobe.Superior Temporal Gyrus.White Matter.
1.4	3.68	56	-40	10	1. 32% Supramarginal Gyrus, posterior division, 14% Middle Temporal Gyrus, temporooccipital part, 9% Superior Temporal Gyrus, posterior division, 4% Angular Gyrus, 2% Middle Temporal Gyrus, posterior division 2. Right Cerebrum.Temporal Lobe.Superior Temporal Gyrus.White Matter.
1.3	3.53	52	-42	18	1. 37% Supramarginal Gyrus, posterior division, 12% Angular Gyrus, 2% Planum Temporale, 2% Middle Temporal Gyrus, temporooccipital part 2. Right Cerebrum.Temporal Lobe.Superior Temporal Gyrus.White Matter.
1.2	3.48	64	-38	26	1. 58% Supramarginal Gyrus, posterior division, 7% Parietal Operculum Cortex, 5% Superior Temporal Gyrus, posterior division, 4% Planum Temporale, 4% Angular Gyrus, 1% Supramarginal Gyrus, anterior division 2. Right Cerebrum.Parietal Lobe.Inferior Parietal Lobule.White Matter.
1.1	3.31	50	-44	14	1. 30% Supramarginal Gyrus, posterior division, 20% Angular Gyrus, 19% Middle Temporal Gyrus, temporooccipital part 2. Right Cerebrum.Temporal Lobe.Superior Temporal Gyrus.White Matter.

In Chinese speakers, significant activations formed three clusters. The first cluster (3.6 ~ 3.1) is located in both right and left hemisphere that covers the Occipital Pole, the Lingual Gyrus, the Occipital Fusiform Gyrus, and the Temporal Occipital Fusiform Cortex including BA 37. The second cluster (2.6 ~ 2.1) is located in the right hemisphere that covers the IFG, the MFG and the Precentral Gyrus. The third cluster (1.6 ~ 1.1) is located in the right hemisphere that covers the temporooccipital part of the MTG, the AG, and the posterior division of the SMG. The Chinese participants used the IFG, the MFG, the AG, the temporooccipital part of the MTG, the posterior division of the SMG in the right hemisphere to contrast pictures from icons.

On the other hand, in English speakers, significant activations formed one cluster. This cluster is located in both right and left hemisphere that covers the Lingual Gyrus, the Occipital

Fusiform Gyrus, the Temporal Occipital Fusiform Cortex, and the Lateral Occipital Cortex. The English participants relied on visual cortexes to differentiate pictures from icons.

As for the group comparisons, Chinese speakers had one cluster of significant activations in contrast to English speakers in this contrast. This cluster is located in the left hemisphere that covers the Postcentral Gyrus, the Precentral Gyrus, and the Superior Parietal Lobule including BA 4, 5, and 7. These areas are associated to motor reactions. There are no significant activations that form clusters in the contrast of English speakers vs. Chinese speakers.

Appendix D: IRB Approval for Study One

OFFICE OF RESEARCH SUPPORT

THE UNIVERSITY OF TEXAS AT AUSTIN

P.O. Box 7426, Austin, Texas 78713 (512) 471-8871 -FAX (512 471-8873) North Office Building A, Suite 5.200 (Mail code A3200)

FWA: 2030
Date: 01/20/10

PI(s): Sheng-Cheng Huang **Department & Mail Code:** **SCHOOL OF INFORMATION** **D8600**

IRB Approval-IRB Protocol #: 2009-11-0044

EXEMPT DETERMINATION OF RESEARCH PROPOSAL

Title: Concrete (Object) vs. Abstract (Concept) Visual Stimuli

Approval Period: 01/20/2010 01/19/2013 *(expires 12am [midnight] of this date.)*
This research project has been approved for a period of up to three years.

Approval determination was based on the following Code of Federal Regulations:
45 CFR 46.101(b):

(2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless:
(i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.

Responsibilities of the Principal Investigator(s):
Research that is determined to be Exempt from IRB review is not Exempt from protection of the human subjects. The following criteria to protect human subjects must be met:

1. The investigator assures that **all investigators and co-investigators are trained in the ethical principles**, relevant Federal Regulations and institutional policies governing human **subject research;**
2. The investigator assures **that human subjects will voluntarily consent to participate** in the research when appropriate (e.g. surveys, interviews) and will **provide subjects with pertinent information**, e.g. risks and benefits, contact information for investigators and IRB chair, etc.;
3. The investigator assures that **human subjects will be selected equitably**, so that the risks and benefits of the research are justly distributed.
4. The investigator assures that the **IRB will be immediately informed of any information, unanticipated problems** that would increase the risk to the human subjects and cause the category of review to be upgraded to Expedited or Full Review;
5. The investigator assures that the **IRB will be immediately informed of any complaints** from participants regarding their risks and benefits; and
6. The investigator assures that **confidentiality and privacy of the subjects** and the research data will be maintained appropriately to ensure minimal risk to subjects.

The above criteria are specified in the PI Assurance Statement and as the Responsible Investigator, you acknowledged you understood and accepted these conditions with the submission of your protocol. Investigators can refer to the University website www.utexas.edu/irb for specific information on training, voluntary informed consent, privacy, and how to notify the IRB of unanticipated problems.

1. **Closure:** Upon completion of the research project, a closure request must be submitted to the Office of Research Support (ORS).
2. **Unanticipated Problems:** Any unanticipated problems or complaints must be reported to the IRB/ORS immediately. For a description of unanticipated problems, please refer to the ORS webpage: http://www.utexas.edu/research/rsc/humansubjects/policies/section7.html#7.3
3. **Informed Consent:** The informed consent procedures laid out within your research proposal must be followed.
4. **Continuing Review:** If the study will continue beyond the approval period, a continuing review application must be filed.
5. **Amendments:** Amendments do not need to be filed with the ORS if the amendments do not change the risk level of the study (for example: increasing sample size, adding or removing co-PIs, adding or removing research sites, or minor modifications to the research protocol that do not affect the risk level). Changes that alter the level of risk to participants must be requested by submitting an amendment application and revised proposal to the ORS prior to those changes being implemented. For a description of the types of modifications that require an amendment application, please refer to the ORS webpage: http://www.utexas.edu/research/rsc/humansubjects/policies/section6.html#635b , or call 471-8871.

If you have questions, please call your IRB Program Coordinator for consultation.

Thank you for your help in this matter.

Sincerely,

Jody Jensen, Ph.D., IRB Chair

Appendix E: Informed Consent Used in Study One

Cover Letter for Internet Research

You are invited to participate in a survey, entitled "**Concrete (Object) vs. Abstract (Concept) Visual Stimuli.**" The study is being conducted by **Sheng-Cheng (Hans) Huang**, School of Information of The University of Texas at Austin, 1616 Guadalupe, D8600 Austin, TX 78701-1213, 512-299-7671, huangsc@mail.utexas.edu.

The purpose of this study is to examine various types of visual stimuli including icons, pictures, English words, and Chinese characters. This survey is designed to allow participants to rate the concreteness and abstractness of individual stimulus. Your participation in the survey will contribute to a better understanding of the semantic attributes of these 500 visual stimuli. We estimate that it will take about **20 to 30 minutes** of your time to complete the questionnaire. You are free to contact the investigator at the above address and phone number to discuss the survey.

Risks to participants are considered minimal. There will be no costs for participating, nor will you benefit from participating. Identification numbers associated with email addresses will be kept during the data collection phase for tracking purposes only. A limited number of research team members will have access to the data during data collection. This information will be stripped from the final dataset.

Your participation in this survey is voluntary. You may decline to answer any question and you have the right to withdraw from participation at any time without penalty. If you wish to withdraw from the study or have any questions, contact the investigator listed above.

If you have any questions or would like us to email another person for your institution or update your email address, please call **Hans Huang** at **512-299-7671** or send an email to **huangsc@mail.utexas.edu**. You may also request a hard copy of the survey from the contact information above.

To complete the survey, click on the link below:
[HTTP://LINK TO SURVEY URL]
The password for the survey is **[PASSWORD]**.

This study has been reviewed and approved by The University of Texas at Austin Institutional Review Board. If you have questions about your rights as a study participant, or are dissatisfied at any time with any aspect of this study, you may contact - anonymously, if you wish - the Institutional Review Board by phone at (512) 471-8871 or email at orsc@uts.cc.utexas.edu.

IRB Approval Number: **2009-11-0044**

If you agree to participate please press the arrow button at the bottom right of the screen otherwise use the X at the upper right corner to close this window and disconnect. Thank you very much.

Appendix F: IRB Approval for Study Two and Three

OFFICE OF RESEARCH SUPPORT

THE UNIVERSITY OF TEXAS AT AUSTIN

P.O. Box 7426, Austin, Texas 78713 (512) 471-8871 -FAX (512 471-8873)
North Office Building A, Suite 5.200 (Mail code A3200)

FWA # 00002030

Date: 09/02/10

PI(s): Randolph G Bias — Department & Mail Code: SCHOOL OF INFORMATION
Sheng-Cheng Huang — SCHOOL OF INFORMATION

Title: Icon vs. Logographical Word Recognition: A fMRI Experiment

IRB APPROVAL – IRB Protocol # 2007-01-0091

Dear: Randolph G Bias   Sheng-Cheng Huang

In accordance with Federal Regulations for review of research protocols, the research study listed above has been re-approved for the following period of time:

Your research study has been re-approved from 10/01/2010 - 09/30/2011 . *(expires 12am [midnight] of this date.)*

RESPONSIBILITIES OF PRINCIPAL INVESTIGATOR FOR ONGOING PROTOCOLS:

(1) Report **immediately** to the IRB any unanticipated problems.

(2) Proposed changes in approved research during the period for which IRB approval cannot be initiated without IRB review and approval, except when necessary to eliminate apparent immediate hazards to the participant. Changes in approved research initiated without IRB review and approval initiated to eliminate apparent immediate hazards to the participant must be promptly reported to the IRB, and reviewed under the unanticipated problems policy to determine whether the change was consistent with ensuring the participants continued welfare.

(3) Report any significant findings that become known in the course of the research that might affect the willingness of subjects to continue to take part.

(4) Insure that only persons formally approved by the IRB enroll subjects.

(5) Use **only** a currently approved consent form (remember approval periods are for 12 months or less).

(6) **Protect the confidentiality of all persons and personally identifiable data, and train your staff and collaborators on policies and procedures for ensuring the privacy and confidentiality of participants and information.**

(7) Submit for review and approval by the IRB all modifications to the protocol or consent form(s) prior to the implementation of the change.

(8) Submit a **Continuing Review Report** for continuing review by the IRB. Federal regulations require **IRB review of on-going projects no less than once a year** (a Continuing Review Report form and a reminder letter will be sent to you 2 months before your expiration date). Please note however, that if you do not receive a reminder from this office about your upcoming continuing review, it is the primary responsibility of the PI not to exceed the expiration date in collection of any information. Finally, it is the responsibility of the PI to submit the Continuing Review Report before the expiration period.

(9) Notify the IRB when the study has been completed and complete the Final Report Form.

(10) Please help us help you by including the above protocol number on all future correspondence relating to this protocol.

Thank you for your help in this matter.

Sincerely,

Jody L. Jensen

Jody L. Jensen, Ph.D.
Professor
Chair, Institutional Review Board

Appendix G: Informed Consent Used in Study Two and Three

Informed Consent to Participate in Research
The University of Texas at Austin

You have been invited to participate in an MRI study. This form provides you with information about the study. Please read the information below and ask questions about anything you don't understand before deciding whether or not to take part. Your participation is entirely voluntary and you can refuse to participate without penalty or loss of benefits to which you are otherwise entitled. If you are a student, your decision to participate or not to participate as a test subject will NOT affect your grade in any course. Upon your request, the research assistant can provide oral explanations of the content of this consent form and details of experimental procedures in Chinese language to accommodate the possible confusion caused by non-native language.

Title of Research Study:
Icon vs. Logographical Word Recognition in a Semantic Decision-making Task: An fMRI Experiment

Principal Investigator(s):

Randolph G. Bias, Ph.D.
Associate Professor
School of Information
rbias@ischool.utexas.edu
512-471-7046

S. C. (Hans) Huang
Graduate Research Assistant
School of Information
huangsc@mail.utexas.edu
512-299-7671

Funding source: *N/A*

What is the purpose of this study?
The experiment is to determine neuronal correlates of icon recognition and to see if these regions differ from or agree with those excited during logographical word recognition. Another purpose is to examine the familiarity effect of stimulus condition between distinctive language groups and the validity of using pseudo words in a decision-making test.

What will be done if you take part in this research study?
If you agree to be in this study, images of your brain will be taken using a General Electric 3.0 Tesla Magnetic Resonance Imaging (MRI) scanner at the UT Imaging Research Center. The MRI scanner is a machine that enables us to acquire images of the brain by manipulating magnetic fields.

If you agree to take part in the study, you may be asked to do some or all of the following:

- Lie on a table that will be slid into the MRI scanner (so that your head and upper body are inside the magnet tube);
- Wear earplugs and/or headphones to reduce the noise made by the MRI scanner (the magnets can make very loud noises);
- Insert your head into a MRI coil or coil frame;
- Have your head stabilized in various ways, such as being fitted with a bite bar, having foam pads placed around your head, or secured with padded straps or braces;
- Have your hands resting on plastic response pads, similar to wearing gloves.

- Lie still throughout your time in the MRI scanner;
- View various visual stimuli and/or listen to sounds. You may be also asked to make judgments, recall certain words or pictures, or make finger, hand, or eye movements.

Before any of the experimental procedures, you will first be screened to ensure you are eligible to safely participate in an MRI study. You may practice what it is like to be in the scanner using the mock scanner and practice the experimental tasks you will be performing in the scanner on a desktop computer in the observation room. **You may leave if at any time you feel uncomfortable or realize you no longer wish to participate.**

Anatomical images (images that show us the structures in your brain) will be obtained during the first and the last 10 minutes of the study. After the anatomical images, functional images will be obtained for about 20 minutes during the presentations of visual stimuli in total of four runs. Functional images are scans that show us how the brain works by illustrating what the brain is actively doing at a particular time. The whole experience of staying in the MRI scanner for this study will take about 40 minutes in maximum. **Upon your request, we can abort the session at anytime if you wish not to continue to finish the whole experiment.**

The Project Duration is: 12 months

Approximate Number of Participants: 20

What are the possible discomforts and risks?
There are no known significant risks or side effects associated with MRI scans. The magnetic fields, at the strengths used, are not harmful and the MRI scanning procedures used are within the Food and Drug Administration [FDA] guidelines for radiofrequency electromagnetic field exposure created by the MRI.

There is a risk if metal objects are near the MRI because they can be drawn into the MRI scanner and that could hurt someone in or near the machine. Metal objects might be in a body if a person has electrically, magnetically, or mechanically activated implants (such as cardiac pacemakers), or clips on blood vessels in their brain, or other metallic objects in their body such as shrapnel, bullets, buckshot, or metal fragments. To protect against this risk, you will be carefully screened for previous exposure to metallic fragments or to implanted devices. You will also be asked to place all metallic and magnetic objects in your possession (e.g. keys, jewelry, credit cards) in a locker outside the MRI room.

Although there are no known risks of an MRI scan to the unborn fetus, we will not let you take part in the study if you are or might be pregnant.

Some people have reported mild discomfort during MRI scans, such as:

- Claustrophobia (fear of enclosed spaces). You will be asked to lie on a table that slides into a horizontal cylinder only slightly wider than your body in all directions and your head will be secured to help you stay still. If you are likely to be uncomfortable or afraid in enclosed spaces, you should let the researcher in charge of the scan know.

- Reaction to noise levels. The MRI scanner makes loud knocking or beeping sounds during scans; earplugs and/or headphones will be provided to help reduce this noise.
- Peripheral nerve stimulation. Because magnetic gradients are used during scans, the possibility exists for peripheral nerve stimulation. If this happens, you may feel creeping or tingling sensations, typically along your arms or lower back.
- Dizziness and nausea which may occur if you suddenly move your head while you are in the MRI and it is active (not in a rest period).
- You may feel some warmth from the radio frequency coils, the cables to the coils, or the response and physiological monitoring devices. The MRI scanner is set so that this heating will be no more than one degree of body temperature.

You may notify the research staff at any time if you feel uncomfortable, no matter what the reason. You will be in contact with the research staff at all times you are in the MRI scanner through an intercom system mounted in the MRI scanner. You will also be told how let the operator know if you wish to immediately stop scanning and be removed from the magnet. The MRI scan can be stopped at any time at your request. If you think that you have experienced a research-related injury, report this to the director of the Imaging Research Center, Russell Poldrack, PhD, (512) 232-4203.

Operation of the MRI scanner and maintenance of any other safety elements will be performed by IRC-approved personnel.

What are the possible benefits to you or to others?
There will be no direct benefits to most of the subjects associated with participation. However, in the unlikely event that a finding of potential medical significance is obtained (see below), you may learn about an unsuspected medical problem.

If you choose to take part in this study, will it cost you anything?
There are no costs to you for participating as a test subject.

Will you receive compensation for your participation in this study?
You will not receive any monetary compensation or class credit for participation.

What if you are injured because of the study?
Many forms of research involve some risk of injury. If any complications arose, the researchers would assist you by referring you to appropriate medical practitioners, but the University has no program or plan to provide treatment for research related injury or payment in the event of a medical problem. If injuries occur as a result of study activity, eligible University students may be treated at the usual level of care with the usual cost for services at the Student Health Center, but the University has no policy to provide payment in the event of a medical problem. In the unlikely event of a research related injury, please contact the principal investigator.

If you do not want to take part in this study, what other options are available to you?
Your participation in this study is entirely voluntary. You may refuse to participate or withdraw at any time without penalty or loss of benefits to which you are otherwise entitled. Nonparticipation or withdrawal will not affect your grades or academic standing.

How can you withdraw from this research study and who should you call if you have questions?
If you wish to stop your participation in this research study for any reason, you should contact the principle investigator: **Randolph G. Bias, Ph.D. at (512) 471-7046** or his research assistant **Hans Huang at (512)-299-7671**. You should also call the principle investigator for any questions, concerns, or complaints about the research. You are free to withdraw your consent and stop participation in this research study at any time without penalty or loss of benefits for which you may be entitled. Throughout the study, the researchers will notify you of new information that may become available and that might affect your decision to remain in the study.

In addition, if you have questions about your rights as a research participant, or if you have complaints, concerns, or questions about the research, please contact Jody Jensen, Ph.D., Chair, The University of Texas at Austin Institutional Review Board for the Protection of Human Subjects, or the Office of Research Compliance and Support at (512) 232-2685.

How will your privacy and the confidentiality of your research records be protected?
Images will be stored on the Imaging Center RAID, with the primary reference field being the study or scan number, which is automatically generated by the MRI system. Personal information linking a participant with a scan will be maintained in a manually generated log, which is stored in a locked cabinet in the Control Room of the Imaging Center. Access to the scan data on the computer is password protected and only available to relevant researchers. The Imaging Center RAID is backed up and archived to the Texas Advanced Computer Center on a daily basis.

All scans and paperwork will be protected to the extent provided by law.

Possible Discovery of Findings Related to Medical Imaging:
If you volunteer for this research study, the MRI scans that we will perform are NOT necessarily equivalent to MRI scans used to diagnose medical problems. Many potentially serious problems may be undetectable on these scans. A negative MRI should not be used to avoid a visit to your primary physician. If you are having physical symptoms that you are concerned about, you should see your primary physician, who will determine the examinations required to arrive at a proper medical diagnosis.

There is a remote chance that imaging may reveal unsuspected findings that are of potential medical importance. Therefore, the anatomical images obtained during your session will be reviewed by a radiologist (a physician trained in the interpretation of medical images). In the unlikely event that your images show clinically significant findings, the investigator will contact you and inform you of the findings in a phone call as well as a follow-up letter. With your permission, the findings will be also reported to your physician. If you do not have a physician, we can recommend one for you. Two weeks after our initial contact to let you know about the findings, we will call again to see if you need any further assistance from us. The decision as to whether to proceed with further examination or treatment lies solely with you and your physician. The investigators, the consulting radiologist, and The University of Texas are not responsible for any medical examination or treatment that you undertake based upon these findings. Because the images obtained in this study do not comprise a proper clinical MRI study, these images will not be made available to you or your physician.

If in the unlikely event it becomes necessary for the Institutional Review Board to review your research records, then the University of Texas at Austin will protect the confidentiality of those records to the extent permitted by law. Your research records will not be released without your consent unless required by law or a court order. The data resulting from your participation may be made available to other researchers in the future for research purposes not detailed within this consent form. In these cases, the data will contain no identifying information that could associate you with it, or with your participation in any study.

Will the researchers benefit from your participation in this study? N/A

Signatures:
As a representative of this study, I have explained the purpose, the procedures, the benefits, and the risks that are involved in this research study:

____
Signature and printed name of person obtaining consent **Date**

You have been informed about this study's purpose, procedures, possible benefits and risks, and you have received a copy of this form. You have been given the opportunity to ask questions before you sign, and you have been told that you can ask other questions at any time. You voluntarily agree to participate in this study. By signing this form, you are not waiving any of your legal rights.

____
Printed Name of Subject **Date**

____
Signature of Subject **Date**

____
Signature of Principal Investigator **Date**

Medical Release

Name and address of Personal Physician______________________________________

____

I hereby agree to have the Principal Investigator or the Medical Director of the Imaging Research Center report to my Personal Physician findings of potential medical significance that might be obtained as a result of my participation in this study.

____

Signature of Subject **Date**

Appendix H: Imaging Research Center Subject Screening Form

University of Texas Imaging Research Center MRI Research Subject Screening Form

Date: ____/____/____ (Month Day Year)   Exam Number: ____________

Principal Investigator: ____________   Level 2 User: ____________

Name: ____________ (Last First Middle Initial)   Age: ______ Height: ______ Weight ______lbs

Date of Birth: ____/____/____ (Month Day Year) Gender: ❑ Male ❑ Female   Body part to be scanned: ____________

Address: ____________ (Street)   Phone number: ____________

____________ (City) ______ (State) ______ (Zip)

1. Have you had prior surgery or an operation (e.g., arthroscopy, endoscopy, etc.) of any kind? ❑Yes ❑No
   If yes, please indicate the date and type of surgery:

   Date: ____/____/____ (Month Day Year) Type of surgery: ____________

   Date: ____/____/____ (Month Day Year) Type of surgery: ____________

2. Have you had a prior MRI imaging study or examination? ❑Yes ❑No

   If yes, please specify:

   Body Part: ____________ Date: ____/____ (Month Year) Facility: ____________

   Body Part: ____________ Date: ____/____ (Month Year) Facility: ____________

   Body Part: ____________ Date: ____/____ (Month Year) Facility: ____________

3. Have you experienced any problem related to a previous MRI examination or MR procedure? ❑Yes ❑No
   If yes, please describe: ____________
4. Have you had an injury to the eye involving a metallic object or fragment (e.g., metallic slivers ,shavings, foreign body, etc.)? ❑Yes ❑No
   If yes, please describe: ____________
5. Have you ever been injured by a metallic object/foreign body (e.g., BB, bullet, shrapnel, etc.)? ❑Yes ❑No
   If yes, please describe: ____________
6. Are you currently taking or have you recently taken any medication or drug? ❑Yes ❑No
   If yes, please list: ____________
7. Are you allergic to any medication? ❑Yes ❑No
   If yes, please list: ____________
8. Do you have a history of asthma, allergic reaction, respiratory disease, or reaction to a contrast medium or dye used for an MRI, CT, or X-ray examination? ❑Yes ❑No
9. Do you have anemia or any disease(s) that affects your blood, a history of renal (kidney) disease, renal (kidney) failure, renal (kidney) transplant, high blood pressure (hypertension), liver (hepatic) disease or seizures? ❑Yes ❑No
   If yes, please describe: ____________

For female participants only: It is crucial that we find out whether there is any chance that you are pregnant.

10. Are you post menopausal? ❑Yes ❑No
11. Are you pregnant? ❑Yes ❑No
12. Do any of the following conditions apply:
    Has it been more than 28 days since your last menstrual period? ❑Yes ❑No
    Are you taking any type of fertility medication or are you having fertility treatments? ❑Yes ❑No
13. Are you currently breast feeding? ❑Yes ❑No

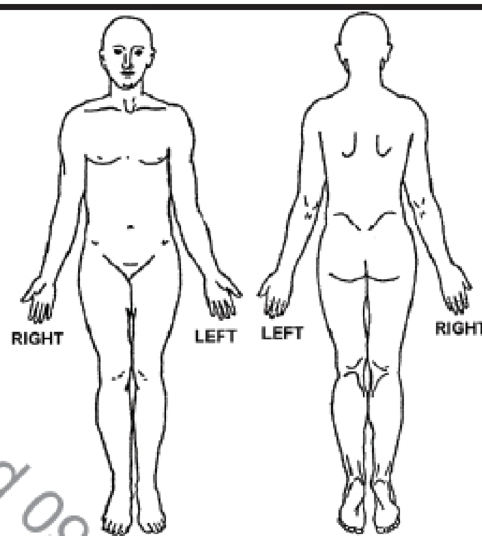
Subject Screening Form Version 090908/Lud

WARNING: Certain implants, devices, or objects may be hazardous to you and/or may interfere with the MR procedure (i.e., MRI, MR angiography, functional MRI, MR spectroscopy). Do not enter the MR system room or MR environment if you have any question or concern regarding an implant, device, or object. Consult the researcher BEFORE entering the MR system room. The MR system magnet is ALWAYS on.

Please indicate if you have any of the following:

☐Yes ☐No Aneurysm clip(s)
☐Yes ☐No Cardiac pacemaker
☐Yes ☐No Implanted cardioverter defibrillator (ICD)
☐Yes ☐No Electronic implant or device
☐Yes ☐No Magnetically-activated implant or device
☐Yes ☐No Neurostimulation system
☐Yes ☐No Spinal cord stimulator
☐Yes ☐No Internal electrodes or wires
☐Yes ☐No Bone growth/bone fusion stimulator
☐Yes ☐No Cochlear, otologic, or other ear implant
☐Yes ☐No Insulin or other infusion pump
☐Yes ☐No Implanted drug infusion device
☐Yes ☐No Any type of prosthesis (eye, penile, etc.)
☐Yes ☐No Heart valve prosthesis
☐Yes ☐No Eyelid spring or wire
☐Yes ☐No Artificial or prosthetic limb
☐Yes ☐No Metallic stent, filter, or coil
☐Yes ☐No Shunt (spinal or intraventricular)
☐Yes ☐No Vascular access port and/or catheter
☐Yes ☐No Radiation seeds or implants
☐Yes ☐No Swan-Ganz or thermodilution catheter
☐Yes ☐No Medication patch (Nicotine, Nitroglycerine)
☐Yes ☐No Any metallic fragment or foreign body
☐Yes ☐No Wire mesh implant
☐Yes ☐No Tissue expander (e.g., breast)
☐Yes ☐No Surgical staples, clips, or metallic sutures
☐Yes ☐No Joint replacement (hip, knee, etc.)
☐Yes ☐No Bone/joint pin, screw, nail, wire, plate, etc.
☐Yes ☐No IUD, diaphragm, or pessary
☐Yes ☐No Dentures or partial plates
☐Yes ☐No Tattoo or permanent makeup
☐Yes ☐No Body piercing jewelry
☐Yes ☐No Hearing aid
(Remove before entering MR system room)
☐Yes ☐No Other implant ____________________
☐Yes ☐No Breathing problem or motion disorder
☐Yes ☐No Claustrophobia

Please mark on the figures below the location of any implant or metal inside of or on your body.



IMPORTANT INSTRUCTIONS

Before entering the MR environment or MR system room, you must remove all metallic objects including hearing aids, dentures, partial plates, keys, beeper, cell phone, eyeglasses, hair pins, barrettes, jewelry, body piercing jewelry, watch, safety pins, paperclips, money clip, credit cards, bank cards, magnetic strip cards, coins, pens, pocket knife, nail clipper, tools, clothing with metal fasteners, & clothing with metallic threads.

Please consult the experimenter if you have any questions or concerns BEFORE you enter the MR system room

NOTE: You are required to wear earplugs or other hearing protection during the MR procedure to prevent possible problems or hazards related to acoustic noise.

I attest that the above information is correct to the best of my knowledge. I read and understand the contents of this form and had the opportunity to ask questions regarding the information on this form and regarding the MR procedure that I am about to undergo.

Signature of person completing form: ______________________ Date: ___/___/___
Signature Month Day Year

Form completed by: ☐Subject ☐Relative ______________________ ______________________
Printed Name Relationship to subject

Form reviewed by: ______________________ ______________________
Signature Printed Name

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He has several academic degrees in engineering, education, and science including one Bachelor's, two Master's and an upcoming Ph.D. His subject of studies has focused on human factors of users' behaviors and cognitive mechanisms that affect the success and failure of HCI design and software usability. He learns how people make mistakes with machines and how machines cause people to make mistakes in order to improve the design of human-machine interfaces. Currently, he has become interested in applying neuroimaging methods of fMRI to study the influences of human cognition and social context that affect symbol interpretations. He believes that his research can help contribute to the knowledge of developing brain-computer interfaces in the long term.

Other than being an overly analytical doctoral student for the past seven years, Sheng-Cheng is a simple person who likes to enjoy and find the meaning of everyday life. He likes to play guitar, be creative with LEGO bricks, and criticize poorly-designed elements in video games. Sheng-Cheng is a Shodan (1st degree black belt) in Aikido, a fan of Ricoh cameras, a first-year recurve archer, and an occasional snowboarder.

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